Evaluating Small Area Population Estimates and Projection for Sub-Council Areas in Scotland

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Abstract

This thesis is a collaborative research project with the National Records of Scotland and seeks to provide a fresh assessment of small area population estimates, and the first evaluation of small area population projections in Scotland. Population estimates and projections are valuable tools for planners and policy makers, with small area population statistics becoming increasingly important as demand grows for more detailed data. From planning school place provision to adequate water services, there are many aspects of planning and policy making which depend on having knowledge of the population size and structure at a neighbourhood level. This research uses a mixed methods approach, evaluating historical estimates and projections using statistical techniques; as well as using qualitative analysis to examine how local users of these statistics engage with, and accommodate for, the potential for error inherent in these estimates and projections. This research focuses in particular on estimates produced by the Cohort Component method currently used in Scotland, comparing this approach to alternative methods such as those employed by other statistical agencies, and less data intensive, simple methods. A significant finding from this comparison is that methods favoured by other UK statistical agencies outperformed the Cohort Component method. Results show that both the Ratio Change method used in England and Wales, and the Average method, used in Northern Ireland, both produced the most accurate estimates. When exploring how these methods varied in accuracy across areas, results also found evidence of bias. The most striking finding from this evaluation was the relationship between estimation bias and deprivation, with population estimates in the most deprived areas, tending to be under-estimated and the most affluent areas over-estimated. This was a finding which was present across all of the complex methods of population estimates that were included in this study, however the effect was strongest for the Cohort Component method. While these findings may suggest that Cohort Component method may not be the most appropriate for producing population estimates, it was the best performing method when evaluating population projections. Here, it was found that this method outperformed all the simple approaches included in this study. However, there is some evidence to support the use of these simpler methods in some circumstances, over short projection periods. While the simpler methods were less accurate than the Cohort Component method, all approaches included in this study met the threshold of 80% of projections within 10% of the true population, which the shelf life literature defines as a reliable projection. This suggests that, over short projection periods, the simple methods can be considered reliable and useful, despite marginally higher levels of error. These simple methods could therefore be recommended to local users who wish to produce their own projections. This desire from users for locally produced statistics was evident in this research. Participants felt that local knowledge, particularly regarding special populations, could improve the assumptions used in producing population statistics. Participants also felt that more could be done to provide greater context to the population change presented in the projections in order for them to be taken seriously by non-expert audiences. Taking these views into account, closer links between national and local bodies, is a key recommendation of this research when considering improving user experience.

Lay Summary

This thesis examines the accuracy of small area population estimates and projections in Scotland, explores how accuracy varies between areas for different methods, and studies how these population statistics are interpreted and understood by local planners.

Population estimates and projections are approximations of the true population size and its age/sex structure, however, they differ in their purpose, with estimates providing population data for the present; while projections demonstrate what the future population would be, should past trends in the population (concerning fertility, mortality and migration) continue. At a local level, such as for small areas within local authorities, these figures are used to allocate funding and resources, planning school place provision, social care services and house building. These estimates and projections provide useful data for planners and policy makers and are used to inform decision making. Local demographic statistics for small areas within local authorities are used to allocate funding and resources and to plan school place provision, social care services and house building. As these estimates and projections are so important for ensuring that public services and funds are allocated effectively and fairly both now and for future years, it is imperative that the users of these statistics are aware of how closely they can expect estimates and projections to reflect the true population, and which methods of producing these statistics produce the most reliable results. This research responds to the need identified above, by comparing estimates and projections in 2011 produced prior to release of 2011 census data to the population counts in the 2011 census. It is this release of the 2011 census which enables this research, as it provides a valuable set of data to compare with estimates and projections of population for 2011, developed prior to the census data becoming available. Since the 2011 Census represents an almost complete enumeration of the population, it offers a gold standard for the ‘true’ population allowing error in population estimates and projections to be established. By quantifying this error in small area population estimates and projections, it not only provides some insight into the expected levels of accuracy of these statistics, but also provides an opportunity to compare the accuracy of different methods and how this accuracy may change across place and time.

As this thesis is a collaborative project with National Records of Scotland, one of the main aims of this study was to compare the accuracy of estimates/projections using the method currently used in Scotland to alternative methods. Some of these alternative methods are those used by other UK statistical agencies while others are simpler methods which can be produced with minimal resources or skill. Within the UK, different estimation approaches are used by each statistical agency (National Records of Scotland, Office of National Statistics and Northern Irish Statistics and Research Agency) to produce small area population estimates, with each of these methods included in the analysis conducted in this thesis. In Scotland the Cohort Component method that is currently used relies on data on a base population that is updated with information on births, deaths and migration to produce small population estimates, while in England and Wales, annual changes in data which act as indicators of the population size (such as GP registrations) are used. In Northern

Ireland, both of these methods are applied, with the final small area estimate being an average of the estimates produced by each single method.

One key finding from this analysis suggested that the current method for producing small area population estimates in Scotland may not be the most effective. While the Scottish method produced more accurate estimates compared to the simpler approaches; it produced less accurate estimates than those produced by the methods employed in England and Wales, and Northern Ireland respectively. This comparison of the accuracy methods used by UK statistical agencies has not been possible before this current research, and therefore provides a new insight into how different methods compare when producing population estimates for small areas across Scotland.

As well as exploring the overall accuracy of population estimates, this thesis also examined how accuracy varies between areas, based upon their characteristics. Results of this analysis found a relationship between the type of error observed in an area (over or under estimate) and an areas levels of deprivation. This significant finding revealed that the most deprived areas in Scotland were routinely under-estimated, with estimates capturing fewer individuals in these areas compared to the truth, while in the most affluent areas, populations were more likely to be over-estimated, where more individuals were recorded in an area compared to the true population. This relationship existed, to some degree, across all estimation methods examined in this analysis, suggesting that a simple change in methods would not address this issue. This finding is significant, as resource allocation and funding based upon population size, may result in deprived areas receiving less than they are entitled to while affluent areas receive more. This therefore has the potential to reinforce and exacerbate existing inequalities.

In addition to evaluating population estimates, the performance of methods used to produce small area population projections were also examined. This is the first research of this type, as population projections for small areas in Scotland have only recently been produced, with little known about the accuracy of these statistics. As the National Records of Scotland are the only UK statistical agency producing population projections of this type, the official method used in Scotland was only compared to simple methods. As with the population estimates, the method currently used to produce small area population projections in Scotland uses data regarding births, deaths and migration to understand how the population may change in the future, while the simple methods are mathematical techniques which continue past population growth trends into the future.

This comparison of projection methods found that the approach currently used in Scotland did produce the most accurate projections for small areas, out-performing all the simple methods. Despite these simpler methods producing less accurate projections, there was some evidence that they could be of some use to local users. When using an evaluation criterion which sets out a threshold of accuracy whereby projections can still be considered useful and effective, it was found that, for short term projections of around five years, these simple methods may produce projections which are just as useful as the current method used in Scotland, with only small differences in levels of accuracy. This suggests that, while the currently used method is the most appropriate for producing small area population projections in Scotland, particularly for long term projections; local users who have a desire to produce their own, short term, projections could use these simple methods, should they lack the resources or experience required to apply the more complex method currently used by National Records of Scotland.

In addition to statistical analysis, the views and experiences of local users were gathered using interviews and questionnaires. This part of the research aimed to explore how these local users understand and accommodate for error inherent in both small area population estimates and projections. Results of these discussions with local users highlighted the importance of local knowledge as an evaluation tool, both when assessing the accuracy and usefulness of population statistics. Using their familiarity with the local community in which they worked, participants in this research cited a number of area-specific issues which they felt could be missed by analysts producing data from centralised agencies. Matters such as links between island communities, limitations in housing stock and quirks regarding temporary populations were all issues identified by participants, which were seen as being missed from official statistics. This highlights the importance of local knowledge within these small areas, and demonstrates the way in which potential inaccuracies present in population statistics can be identified and taken into account before being used to inform local decision making. These results also stress the importance of ongoing communication between local and centralised agencies; with local users familiar with the geography of an area best placed to advise remote analysts on how small areas should be defined, in order for these population estimates and projections to be useful.

Overall, this research evaluated small area population estimates and projections in Scotland from a number of perspectives, both using statistical techniques to compare different methods for producing these statistics and exploring how accuracy varies between areas; and using discussions with individuals who use these statistics to explore how they employ their local knowledge to identify potential errors.

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Declaration

1. I declare that this thesis has been composed solely by myself and that it has not been submitted, in whole or in part, in any previous application for a degree. Except where states otherwise by reference or acknowledgment, the work presented is entirely my own.

2. I confirm that this thesis presented for the degree of Doctor of Philosophy, has

i) been composed entirely by myself

ii) been solely the result of my own work

iii) not been submitted for any other degree or professional qualification

3. I declare that this thesis was composed by myself, that the work contained herein is my own except where explicitly stated otherwise in the text, and that this work has not been submitted for any other degree or processional qualification except as specified.

Signed: *S.Christison* Date: 16/06.2020

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Abbreviations

APE – Absolute Percentage Error

AP”E” - Absolute Percentage “Error”

NISRA – Northern Irish Statistics and Research Agency

NRS –National Records of Scotland

ONS – Office of National Statistics

PAMS - The Population and Migration Statistics Committee (Scotland)

SIMD – Scottish Index of Multiple Deprivation

UN – United Nations

Chapter 1: Introduction

1.1: INTRODUCTION

Since 1801 the census has provided a comprehensive indication of population size and age/sex structure, however as the census is only carried out once a decade, there is a gap in demographic statistics in the intervening years. For this reason, techniques for estimating the population in the intercensal years have been developed, as well as methods for projecting how the population may change in the future. These estimates and projections provide valuable information to planners and policy makers in a variety of sectors, however in Scotland there is little knowledge to date, regarding the reliability of these figures, particularly for sub-council areas within local authorities. This research seeks to evaluate a range of approaches used to produce population estimates and projections for small, sub-council areas in Scotland. This project was conducted in collaboration with National Records of Scotland (NRS), the non-ministerial department of the Scottish Government who produce the official population statistics. As a collaborating partner, NRS provided support in the form of data and desk space within National Records of Scotland, as well as guidance and feedback when developing the analysis and methodology used in this thesis. Funding for this project was awarded by the Scottish Graduate School of Social Science as part of a studentship, funded by the Economic and Social Research Council.

The purpose of this thesis is to compare the performance of a range of estimates and projections produced using a variety of methods, from the Cohort Component method currently used in Scotland, to approaches used by other statistical agencies in the UK, as well as simple methods. In addition to assessing the performance of each of these methods, this project also aims to explore the demographic factors which may influence the accuracy of these statistics, modelling the way in which area characteristics influence accuracy and to determine whether some areas are more prone to 'error' compared to others. This research aims to be the first Scottish analysis of both small area population estimates and projections. While sub-council level population estimates have previously been examined as part of a broader, Britain wide evaluation conducted by Lunn et al (1997) focusing on 1991 demographic data, there has been no study into the performance of Scottish small area population estimates, in their own right. Similarly, as sub-council area population projections are a new endeavour for the National Records of Scotland, and the only sub-council projections produced in the UK, there has been no previous research conducted into their performance.

While these population statistics are also produced at national and council levels of geography, this research will focus on sub-council level areas. When studying population data, Smith and Morrison (2005) explain that the problems associated with small area demographics differ from larger geographies. When producing estimates and projections for small areas, there are many challenges which analysts may face. When dealing with small areas, populations are more volatile and vulnerable to change compared to larger, national geographies, while the data required to produce estimates and projections is more difficult to acquire at a local level. Despite these challenges, there has been a growing demand for these small area population statistics, with increasing levels of detail and precision expected. This project will not only evaluate a range of methodologies in terms of quantitative precision, but will also engage with users of small area estimates and projections to gauge the way in which these statistics are used and interpreted and how users accommodate and understand the error present in estimates and projections.

1.2: IMPORTANCE OF SMALL AREA POPULATION DATA

Both small area population estimates and projections have a wide range of uses across a range of organisations and sectors, covering health services, allocating public services and funding, commercial services and many more which will be discussed in greater depth in Chapter 2. Rees et al (2019) describe how these population statistics are not only used directly as an indication of the services and resources required to meet the needs of the population, but are also used in the production of secondary statistics such as mortality rates or levels of deprivation. Currently, the NRS produce small area population estimates on an annual basis, while new, experimental, small area population projections were only produced in 2016, and will be updated regularly by the Improvement Service from 2020. This new development in producing population projections in sub-council areas comes in response to demand from local users who have expressed a desire to have projections for sub-council geographies, to assist them with planning housing land allocations, service planning and more local planning tasks such as the provision of school places and social care services (NRS, 2016). As these statistics inform so many aspects of decision making, both now and in the future, any inaccuracies present in these statistics have the potential to have a very real impact upon individuals' everyday lives.

As well as having reliable population figures for the areas as a whole, age-specific population data provides an additional level of detail which can more effectively inform planning and policy making. Providing age structure within a population estimate or projection could be seen as one of the most useful details which can be included in demographic data. While statistics for the total population are valuable to some extent, they provide only a limited insight into the composition of the population. As discussed previously, population statistics have a range of uses for planners and policy makers, such as aiding decision making when allocating funding, resources and infrastructure. However, in many cases, resources and infrastructure projects, such as schools or social care for the elderly, are linked to particular age groups. As Lunn et al (1998:327) explains, *"Because resource allocation is often targeted at specific age-groups, knowledge of the accuracy of age-specific population estimates is crucial for both users and producers"*. For this reason, this research will primarily focus on evaluating age-specific population statistics.

It is generally accepted that small areas are subject to higher error in demographic statistics than are larger areas. This is because small areas are particularly susceptible to rapid growth or decline in population, or due to substantial changes in terms of age structure (Hoque 2008). However, in order for these statistics to be used effectively, it is necessary to have an indication of the range of uncertainty which may be expected from these figures. In this research, the level of inaccuracy present in small area population estimates and projections produced using a range of complex and simple methods will be quantified. While this project will primarily focus on the performance of population statistics produced using the Cohort Component method, which is one of the most commonly used methods for producing population estimates and projections (Burch, 2018), in order to understand the accuracy of this approach, it must be understood in the wider context of the range of accuracy present in estimates and projections produced using alternative methods.

1.3: SCOTLAND AS A STUDY AREA

As this is a collaborative project with the National Records of Scotland, estimates and projections produced for Scottish sub-council areas will be the focus of this research. This attention given to population statistics for small areas in Scotland makes a significant contribution of knowledge, both in the field of demography and for planners and policy makers in Scotland. While there have been many research projects which have been previously conducted comparing small area population estimate and projection methods (Isserman, 1977; Smith & Cody, 2004; Hoque, 2012), there has been little evaluation of small area population estimates, and no previous evaluation of small area population projections in Scotland, partly as these were not produced by National Records of Scotland until 2016.

While Scottish small area population estimates have been included in previous studies which have evaluated small area estimates for Britain as a whole, (Lunn et al, 1998), there has been no study of Scottish small areas in their own right. Since the Estimating with Confidence project was conducted almost thirty years ago, the political structure of Scotland has changed dramatically. The most significant change over this time period, is the establishment of the Scottish Parliament in 1999 and the devolution of a range of powers from Westminster to Holyrood. As the Scottish Government is now responsible for a range of policy issues, including housing, the environment, education, health and social care, economic development and many more, with new powers over taxation added in 2016 (Scottish Parliament, 2018), the role of population estimates and projections for informing planning and policy making have become increasingly important. In response to the renewed importance of small area population statistics, National Records of Scotland have been working to develop new geographical areas to effectively and fairly capture the population of Scotland. Since Lunn et al's (1997) study of 1991 estimates, new geographical sub-divisions called data zones have been introduced. These data zones are now the principal, core, small area geography, designed to consistently capture populations of between 500 and 1000 people and can be used as the building blocks for larger geographical areas (NRS, 2018). This change from the small areas which were examined in the study by Lunn et al (1997), to data zones which were first introduced in 2001, again highlights why a more up-to-date evaluation of small area statistics is necessary to reflect these changes.

In addition to devolution of powers, in the last 30 years, there has also been some substantial restructuring of local government, introduced with the Local Government etc (Scotland) Act 1994. This act, introduced by John Major in 1994, removed the two tier system of local government in Scotland which consisted of 3 island councils, 9 regional councils and 53 district councils, and replaced them with 32 local authorities which exist to this day (Fairly, 1995). This change may be the most important difference between the research conducted for this thesis and the previous research carried out by Lunn et al (1997) which evaluated population estimates in 1991. Lunn et al (1998) collected small area population estimates developed by local planners and found that, in Scotland, these were largely produced by regional councils. This research will seek to explore whether the local authorities which exist today have the capacity or desire to produce in-house population statistics, since the restructuring of local government whereby regional councils, which bore a majority of the research responsibilities, were disbanded.

This thesis will also include the only evaluation of small area population projections in Scotland to date. In 2016, NRS released their first experimental population projections in response to demand from local users such as council staff and community groups to aid decision making when allocating local funding and resources (NRS, 2016). While projections for larger areas of geography such as council areas, NHS board areas and national parks (NRS, 2018) are produced every two years, so far, there has only been one set of sub-national population projections produced, although these statistics are growing in importance and will be regularly updated by the Improvement Service in Scotland from 2020 onwards. Due to the fact that population projections for all sub-council areas in Scotland have only been available for a limited period, the opportunity to evaluate these statistics has only arisen in recent years. As a result, this thesis will provide the first comprehensive evaluation of the methodology used to produce these new small area projections for the whole of Scotland, providing some indication of the success of this new endeavour for the National Records of Scotland.

Overall, taking into account all the changes which have occurred in Scotland over the last 30 years, a fresh evaluation of the accuracy of small area population estimates, and a first evaluation of small area projections is required. While there has been some limited evaluation of small area population estimates in Scotland (Snowling, 2009), the subsequent release of the 2011 census allows a more comprehensive evaluation than was possible previously. This research seeks to address this lack of knowledge regarding the performance of current population statistics in Scotland by building on previous research, evaluating this data not only from a quantitative perspective but also examining the way in which local government users employ these figures in their work, accommodate error and whether local users produce their own statistics or rely solely on the official statistical releases produced by NRS.

In an academic sense, it could also be argued that the geographical distribution of the population of Scotland and the distinct characteristics found in particular areas of the country, from urban to very remote areas, make Scotland an interesting case study. Scotland offers a diverse set of area characteristics to evaluate the accuracy of population estimates and projections according to different methods. The geography of Scotland contains a multitude of area types, with different age profiles, population densities and levels of inequality. Anderson and Roughley (2018;4) stress this point writing that; "*No serious scholar of Scottish geography, economy, or social or cultural patterns would ever treat Scotland as a homogeneous country or show no awareness of diversity within it".* While Scotland is a small country geographically, it contains a vast array of different types of area, from densely populated cities and commuter towns in the Central Belt to sparsely populated Highland towns and villages and more inaccessible island communities, with some of these area types existing within a single local authority. It is therefore important to not only consider how the particular areas may attract certain demographic groups, which may in turn influence the drivers of population change, (and in turn error in demographic estimates/projections), but also how the physical geographies of particular areas may impact upon individuals' behaviour. When focusing on small areas, and in particular the way in which area characteristics may influence the accuracy of population statistics, the difference in small areas across Scotland should be acknowledged. Anderson and Roughley (2018:4) further highlight this issue; "*Scotland as a country is sometimes a meaningful unit of analysis. But it is also important to be sensitive to regional and local patterns and trends, and to the particular factors which generate them. Indeed, the demography can often only be understood in these more localized contexts and it is the aggregate of these different, and often conflicting, patterns and trends which ultimately produce Scottish national totals and rates".* It is these differences between local areas which will be a key issue in understanding the factors which may impact upon the accuracy of small area statistics. It is therefore important that the area of study, in this case sub-council areas in Scotland, have a wide range of area types in order to fully explore the way in which methods for producing these statistics perform differently in different circumstances.

1.4: KNOWLEDGE GAP

As well as making a novel contribution to what is known about the accuracy of small area population statistics in Scotland, this project also aims to build upon existing research in this field. While previous research has largely sought to evaluate population estimates and projections from a purely quantitative perspective (Marshall et al, 2017; Smith & Sincich, 1992; Wilson, 2015), this research will combine a statistical evaluation of small area population estimates and projections with the views and experiences of individuals who routinely engage with these statistics. By using qualitative approaches, this project seeks to not only provide an indication of the level of accuracy present in population statistics, but to connect empirical evidence on accuracy with the ways in which these demographic statistics are used in the local planning process. The inclusion of both an empirical analysis of 'error' and of the practical applications of these demographic statistics not only provides a contribution to academic knowledge but also to the policy makers and statisticians who produce and use them.

While taking a purely quantitative approach to this analysis would provide valuable results, giving an indication of the level of accuracy which may be present in small area population statistics and help to inform users of the most reliable methodology, for this project to have a meaningful impact beyond a numerical evaluation, the experiences of local users must be taken into account. In this research, users of these statistics will be consulted to understand how they account for 'error' when using statistics for planning as well as their expectations of accuracy and level of detail for small geographical areas. It is by combining the results of the statistical analysis which will quantify a range of expected accuracy, along with the accounts from users which brings potential for improvement in the use of population statistics and the way in which they are communicated.

In addition to being one of the first evaluations of small area population estimates and projections in Scotland, this project is the first to compare the Cohort Component method which is currently used to produce the official small area population statistics, to alternative methods. This research will evaluate a range of methods, including simple approaches which could prove less data intensive, and might be implemented by local planners, as well as approaches which employ alternative, administrative data sources. This comparison of the method which is currently used by National Records of Scotland to alternative approaches is useful in identifying the best approach for producing small area population statistics which may vary according to place or population age group.

In addition to modelling error in local demographic statistics this thesis will also consider the issue of bias in relation to area characteristics. Population size (estimated or projected) is often used to allocate resources and therefore systematic bias in relation to particular area characteristics may lead to resources being distributed unfairly. If particular area types are consistently over or under-estimated, it may indicate methodological issues with particular approaches in which certain demographic groups are missed or over-counted or that some components of population change, for example migration, are poorly captured. By exploring how particular areas may be over or under estimated, this project may highlight issues in resource allocation which could have the potential to negatively impact upon the public.

1.5 INTERNATIONAL CONTEXT

While there has so far been little research into the accuracy of small area population estimates and projections in Scotland, there has been analysis conducted in other nations which have also sought to measure the accuracy of official small area population estimates and projections using census data. The existence of these studies stresses not only the importance of evaluating small area population statistics as an area of academic study, but also highlights the lack of this type of research within the UK, and in particular Scotland. While there has been some research conducted previously in the UK, as previously discussed with reference to Lunn et al's (1998) Estimating with Confidence Project and Marshall et al's (2017) evaluation of small area population estimates in England and Wales, this section will explore the international context in which this research will sit, and highlight its place within the existing academic literature.

One such study which has previously evaluated the performance of small area projections was carried out by Smith and Shahidullah (1995). In this study, small area population projections produced for a sample of census tract areas in the US state of Florida were evaluated. These census tract areas are considered ‘small areas’ and are designed to have an average population of 4,000, but populations can range between 1,200 and 8,000 (US Census Bureau, 2019). This makes these areas somewhat comparable to the SCAP areas used for producing small area population projections in Scotland. Similar to the approach taken in this thesis, Smith and Shahidullah (1995), produced projections for a historical time period, in this case 1990, in order to compare the projected population to the observed population recorded in the 1990 census. This study in Florida also explored how accuracy of projections varied between census areas, based upon area characteristics such as population size and growth, as well as comparing a selection of different methods. This further mirrors the approach taken in this current research which also seeks to compare the accuracy of a range of methods for both population projections and estimates and explore how particular area characteristics may impact upon accuracy.

Alongside this research by Smith and Shahidullah (1995), there have been many similar studies which have been carried out in the US, (Rayer & Smith, 2010; Isserman, 1977; Chi and Voss, 2011), all of which focus on the accuracy of small area population projections for census tract or subcounty areas. While there are many studies which focus on the US, there have been some studies conducted elsewhere in the world. One such study was conducted by Wilson and Rowe (2011), who evaluated the accuracy of population projections produced for Local Government Areas in Queensland, Australia. In this research, Wilson and Rowe (2011) compare more simple, linear extrapolation methods to the official projections produced for small areas in Queensland and explore which areas are prone to higher levels of error. Overall, this research recommends that different methods for producing small area population projections should be compared in order to ascertain whether a method can be considered consistently superior to other methods. Wilson and Rowe (2011) also suggest that methods should be evaluated from an empirical and conceptual standpoint, not only measuring the accuracy of projections, but also considering ow difficult each method would be to apply. In this thesis, some of these recommendations will be addressed, with this current research aiming to evaluate a range of methods for producing both small area population projections and estimates, as well as using qualitative methods to better understand how users of these statistics understand error and considering whether higher levels of error would be acceptable in exchange for methods which would be more accessible to less experienced or skilled analysts.

Another study which has directly evaluated the statistical output released by a national statistical agency was conducted by Cameron and Poot (2010) who evaluated the accuracy of past sub-national projections produced by Stats NZ, the New Zealand statistical agency. While this study focuses on sub-national population projections which are larger areas of geography than those covered in this thesis, there are some aspects of this research explore the issue of projection error in a different way. Although this agency produces a set of variant projections, Cameron and Poot (2010) compare the medium variant 1991-based sub-national population projections for 2006, to the usually resident population recorded in the 2006 census.

Results of this analysis suggested that these projections were ‘overly conservative’, and show some evidence of bias, with faster growing areas systematically under-projected and slower growing areas over-projected. While the comparison between this research by Cameron and Poot (2010) and the analysis conducted in this research is limited due to differences in size of the areas studied, the issue of over and under estimation highlighted in this research is particularly interesting as both types of error can have very different implications when using these figures for planning and policy making. Davis (1995:4) explain this stating that, “*underestimates of future population levels may readily result in crowded public facilities and subsequent costly crash programs for expansion, while overestimates may lead to excess capacity and overstaffing and thus to a misallocation of resources”.* These findings therefore highlight the importance of not only measuring the absolute error but also the direction of error, and how area characteristics may influence the type of error observed. This issue of bias and direction of error will therefore be examined in relation to the estimates and projections evaluated in this current research, comparing the direction of error observed across different area types.

While these studies help to situate this current research in the wider context of the existing literature and provide some insight into the accuracy of small area population estimates and projections in their respective countries, as Wilson (2015:336) states with regards to studies conducted in the US, *“There is no guarantee those findings will be relevant for other countries”.* For this reason, there is still a great deal of value in studying the accuracy of small area population estimates and projections in Scotland, despite similar studies having been carried out elsewhere in the world. This study also seeks to provide a more comprehensive evaluation of small area population statistics compared to these previous studies by including all of Scotland’s small areas rather than a select sample of areas as used in previous research of this type, as well as the inclusion of an analysis of small area population estimates, alongside the evaluation of small area projections.

1.6: THESIS STRUCTURE

This thesis is divided into nine chapters, including three analysis chapters which will seek to evaluate different aspects of small area population statistics in Scotland. Following this first introductory chapter, the first Literature Review (Chapter 2), will explore the importance and history of small area population statistics, focussing on why demographic change varies across small areas, how local demographic estimates and projections are used by planners and finally what small area population statistics contribute to public life.

Chapter three will then provide an overview of the wide range of methods which have been developed to produce both small area population estimates and projections. This review of methods informs the comparison of methods that is carried out in analytic chapter 5 (population estimates) and chapter 6 (population projections).

Following these Literature Review Chapters, the Methodology and Data Chapter (Chapter 4) will describe methodological approaches taken in this research as well as the sources of the data which is used in the analysis. This chapter will identify the specific methods which were used to produce the population estimates and projections evaluated in this project. The statistical approaches used in this evaluation and the data required are also defined in this chapter. As well as the quantitative methodology, the approaches taken to conduct the qualitative analysis is outlined in this chapter, along with the rationale behind why particular approaches were used.

The fifth chapter in this thesis is the first of the analysis sections and evaluates the small area population estimates in Scotland. This chapter, assesses the performance of the Cohort Component method used by National Records of Scotland in their official statistics, as well as a set of alternative methods. In addition to comparing overall accuracy, multilevel modelling techniques are used to explore the way in which area characteristics may affect the accuracy of estimates, and how any possible relationship between area characteristics and estimate accuracy may differ between methods and age groups. By exploring how different area characteristics influence the accuracy of estimates produced by a range of approaches, it may be possible to conclude that some methods are more appropriate for some areas, or age groups, compared to others.

Chapter 6 in this thesis evaluates the accuracy of small area population projections in Scotland. Following a similar process to that used in the previous chapter, this chapter will first evaluate the Cohort Component method for population projections used by National Records of Scotland before comparing its performance to alternative, simpler methods. As in the previous chapter, this analysis of projection methods will also examine if any relationship exists between the performance of each method and area characteristics and age groups.

The seventh chapter in this thesis turns to the qualitative analysis, exploring views and experiences of the professionals who use small area estimates and projections for policy and planning purposes. This chapter explores the responses to a questionnaire and a series of six in-depth interviews. This chapter updates Lunn et al's (1997) previous research, to further knowledge of how local analysts understand, use and produce small area demographic data. This research focuses on the views and experiences of local users in Scotland, relating the responses from these analysts to the findings of the analysis conducted in Chapters 5 and 6

Following the analysis chapters, Chapter 8 of this thesis provides a discussion of the results of the analysis presented in chapters 5, 6 and 7 with reference to the literature reviews in earlier chapters. In this discussion chapter, the findings of this research will be interpreted and explored, taking into account all of the results of the analysis carried out throughout this thesis and evaluating the strengths and limitations of the current analysis. In a practical sense, these findings will also be used to more clearly understand what the results mean for the production of small area population statistics in Scotland.

The ninth and final chapter of this thesis will cover the concluding comments. This section will highlight the key academic and policy contribution of this research.

Chapter 2: Academic and Theoretical Framework of Local Demographic Change

2.1: INTRODUCTION

Developing methods to understand population change is not a new practice, but has existed for hundreds of years as philosophers and policy makers have sought to ensure the resources required to sustain a growing population (de Gans, 2012:xi). Booth (2006) describes how during the last 25 years, demographic forecasting as a discipline has progressed with new methods and models being developed. In particular, the demand for small area population estimates and projections is growing, with users requiring evermore detailed demographic data (Rao & Molina, 2015). As these small area statistics are becoming increasingly important for informing tasks such as resource allocation and public policy, it is also important to understand how reliable these statistics are. As the aims of these estimates and projections are to effectively capture changes in the population, it is important to understand the factors and processes which influence population change and in particular local unevenness in demographic change across small areas. This chapter aims to examine the key literature exploring spatial variation in population growth, focusing on how differences in growth varies between areas and demographic groups and why this matters to demographers.

This chapter will be divided into three sections. The first section will examine the demographic and social theories which exist, to account for why such variation may occur, before examining why this variation in population growth between small areas is important to planners and policy makers in section two. The final section will then review the challenges in capturing local variability in demographic estimates and projections across small areas.

2.2: SPATIAL UNEVENNESS IN POPULATION STRUCTURE AND CHANGE

When examining patterns in the demographic profile of an area or understanding the way in which these demographics change over time, it is evident that there are differences between areas, with the populations of some areas growing more rapidly compared to others or particular types of areas attracting specific demographic groups. In this section, the theories which have been developed in the fields of demography and sociology will be explored to explain why such differences may exist, with references to specific examples of differences between social groups, based upon age, ethnicity or class. Exploring these theories to further understand why spatial differences in demographics exist between small areas, will also aid the interpretation of results discussed in subsequent chapters when exploring differences in error both between areas and methods, as well as why policy makers and planners require demographic estimates and projections for local areas.

2.2.1: Social Spatial Clustering and Habitus

When considering theories within the demographic literature which explore spatial variation in population growth at a local level, it is first important to understand how local communities organise themselves, how demographic groups may cluster together and how this clustering may influence behaviours related to the drivers of population change. In this section, theories concerning this social clustering and shared behaviours will be explored using the theories of socio-spatial clustering and habitus.

Socio-spatial segregation describes *"situations where members of one social group (races, ethnicities, classes etc) are not distributed uniformly over space in relation to the rest of the population"* (Korovina, 2012:3). Such segregation may not be enforced through any formal policy but rather be understood as a social phenomenon. One theoretical framework through which this social clustering can be understood is Bourdieu's theory of Habitus. Inglis and Thorpe (2012:213) describe habitus as a structural social theory which explains the "*characteristic ways of thinking, feeling, acting and experiencing shared by all members of a certain group of people*". This involves the socialisation of individuals as a member of a social group, whereby a group member exhibits similar behaviours and attitudes of the wider group to which they belong. The theory of habitus occurs frequently in literature regarding population change and demography as the theory can be used as a framework to explain how some demographic groups cluster in particular communities and how these clustered social groups impact upon their behaviours regarding fertility, health and migration.

One way in which this social clustering of groups which shared characteristics can impact upon population change can be seen in research from Pearce (2013). In this research, it was suggested that area effects can have an impact upon health outcomes and mortality rates through a process which was described by Pearce (2013:92) as the 'Social Environment'. This theory describes how social cohesion and the social norms of an area can impact upon behaviours which influence health outcomes. An example of this was observed by Lochner et al (2003) in Chicago where it was found that there was some evidence to suggest that areas with higher levels of social capital, a concept developed as part of Bourdieu's theory of Habitus, had lower levels of neighbourhood mortality rates, even when adjusting for neighbourhood deprivation.

Another theory related to population change which is strongly linked to this theory of habitus is gentrification. This concept refers to the changing of communities from predominantly working class areas to the home of a 'new middle class' (Boterman, 2012). First identified by Glass in 1964, the term gentrification refers to the displacement of working class residents by middle class 'invaders', in mostly urban centres, resulting in the demographics of an area being transformed. Boterman (2012) describes how these gentrified communities are largely populated by younger middle class professionals who share a 'metropolitan habitus', with these areas attracting a specific demographic group, based upon both age and class, while Warde (1991; 227) defines gentrification as, "*a process of resettlement and social concentration, a process of displacement of one group of residents with another of* *higher status, entailing new patterns of social segregation".* From this perspective, the theory of gentrification can be understood as a process through which social clustering takes place, not only through the selective migration of the middle class into an area, but also through the displacement of the previous lower class residents who are pushed away from the newly gentrified neighbourhoods and into more deprived areas.

Research conducted by Bondi (1999) highlights the way in which the social clustering through the process of gentrification can impact upon the demographic change occurring in these areas. In this research which examined fertility rates in gentrified neighbourhoods in Edinburgh, Bondi (1999) noted that the population of these areas were predominately made up of professional young women and that these neighbourhoods had lower levels of fertility compared to other areas. In addition to this it was also found that these areas experienced higher levels of population turn over, suggesting that when these women were having children, they moved out of the area. This process of migration behaviours being triggered by lifestyle or stages in an individual's life can also be understood using migration theories which will be discussed later in this chapter.

These examples in Edinburgh and Chicago given by Bondi (1999) and Lochner et al (2003) respectively demonstrate how particular areas attract certain demographic groups, based upon factors such as class and age, and how this clustering of these groups, who share demographic characteristics, impact upon behaviours which influence change within the population of an area. Diez Roux (2001) warns that while studies into area effects cannot directly determine whether it is the characteristics of an area, or the profile of those living in an area that is responsible for geographical differences in population change; neighbourhood effects and area characteristics are important factors to consider when accounting for differences between areas.

2.2.2: Demographic Transition Theory

Demographic Transition theory is an important concept within the field of demography, used to help account for changes in fertility and mortality rates based upon the social and cultural context of the time. Rowland (2003) describes how demographic transition theory can be understood as less of a theory and more as a set of observable trends which ultimately underpin the main theoretic interests of demography.

This description of demographic transition as an observed progression of fertility and mortality trends over time is also emphasised by Singh (1998) who describes the five stages of transition which make up this theory. Each of these stages describes a society's rate of population growth based upon their fertility and morality rates, for example, the first stage describes a society with slow or stationary population growth as a result of high levels of both mortality and fertility; while the fifth stage describes a society experiencing population decline due to low fertility and mortality rates but with deaths outnumbering births. In western societies today, it is understood that they are currently in the fourth stage of transition, which is defined by slow population growth brought about by low rates of both fertility and mortality (Trpkova-Nestorovska et al, 2018).

While the demographic transition theory can provide a useful framework to help define the character of population change at a particular moment in time, transitions into different stages of development do not occur simultaneously, with Lesthaeghe (1995) explaining that these changes occur in areas at different times and do not affect all social groups to the same extent. Research conducted by the World Bank (2011) found similar patterns in spatial differences in demographic transitions across the Middle East and North Africa, with fertility rates declining in urban areas ahead of changes observed in rural areas. In their report, the World Bank (2011) illustrate these spatial differences using fertility data from Iran. In this example, the fertility rate in urban areas began to decline in 1986 at a faster rate than in rural areas, widening the existing gap in the birth rate between these areas. However, by 2000, fertility rates in rural areas also began to decline, reducing the spatial disparity in fertility rates, with only a small difference in the births per woman in urban and rural areas. This could be seen as an instance where the fertility element of the demographic transition evolved differently based upon the demographic profile of an area, with changes occurring in urban communities ahead of rural areas.

This example demonstrates that demographic transitions do not occur uniformly between regions, but rather varies both in terms of the onset of the transition and the rate at which it occurs. This variation can be attributed to differences in the political, economic and social factors which trigger and drive each of the stages of the transition (Willekens, 2014). The issue of economic factors and their role in triggering demographic transitions may be particularly important to consider when focusing on why differences in population growth may exist between small areas, with demographic transitions impacting upon social groups differently, with differences most commonly observed based upon social class. Dribe and Scalone(2014) describe how, throughout all the stages of the demographic transition observed in Western Europe, change occurred at different rates based on class, with the fertility rates of middle class and professional individuals beginning to decline prior to those from lower socio-economic or agricultural backgrounds. While the fertility rates of individuals from lower socio-economic backgrounds did decline in time to mirror those of the upper classes, the differences in the onset of the decline demonstrate that variation in the demographic transition may result in uneven fertility rates between geographies, in turn influencing the growth rate of particular areas.

As well as socio-economic factors impacting upon fertility rates, class differences can also result in the variation of mortality rates. Demographic transition theory is also defined by changes in mortality, with the fourth stage of the transition defined by low mortality rates as well as declines in fertility. However, as with the fertility rates, declines in mortality and improvements in life expectancy also vary between areas, with socio-economic factors playing a major role in geographical disparities in health outcomes. An example of this has been observed in England, where between 2010/12 and 2014/16, the life expectancy in the most deprived areas increased more slowly compared to the least deprived areas (Public Health England, 2018). A similar trend may be present in Scotland, with research examining mortality rates in

Glasgow finding that, despite improvements in life expectancy across all deprivation deciles, there still existed ‘stark inequalities’ based upon area deprivation (Baruffati et al, 2019). This suggests a similar pattern to that recorded in England, with improvements in life-expectancy occurring at different rates based upon area deprivation.

While the demographic transition theory is significant when understanding trends in population growth, related to shifts in fertility and mortality rates; when considering how population change varies between areas, it is important to acknowledge the role of place and demographic factors in influencing when, and at what rate these transitions occur. As discussed earlier in this section, there exists not only spatial differences in the rate of transition, but also differences between demographic groups, as seen in the examples given above where socio-economic status was linked to changes in fertility and mortality rates. When considering the theories of social clustering and habitus outlined in the previous section, the clustering of demographic groups could also be attributed to differences in transition rates between small areas. Differences in growth rates between areas could therefore be attributed to differences in the onset and rate of demographic transition, based upon the demographic profile of the population of an area.

2.2.3: Life Course Theory

Life course theory is another theoretical concept which can provide a framework through which to understand unevenness in population size, age structure and development. While the theories of Habitus and clustering demonstrate that populations in particular areas share similar characteristics, life course theory explains how people align themselves with particular groups at particular points in their life, and in turn, how this influences behaviours linked to drivers of population change.

This theory is becoming a more common feature of population studies with Kulu and Milewski (2007:568), defining the life course as, “*a series of transitions or life-events, which are embedded in careers that give them distinct form and meaning*”. They further explain how life course events such as education and career trajectories can influence migration and child-bearing decision making. This example of education as a life event which can impact upon the timing of children or a trigger for migration is important, as it highlights that the same life course is not shared by everyone but varies depending upon events which occur in individuals’ lives.

One example of differences in the life course can be seen in previous research which has examined differences in fertility based upon ethnicity and class. Research by Dubuce & Haskey, (2010) found that variation in fertility rates between ethnic groups may be due to differences in their engagement with higher education and employment. They explain that Bangladeshi and Pakistani women, who tend to have higher rates of fertility, are less likely to engage in employment, while Chinese women who tend to pursue higher education and training, are more likely to delay fertility and have fewer children.

In addition to this research by Dubuce & Haskey, (2010), it has also been suggested that the life course may also differ based upon socio-economic factors. Wilkinson and Picket (2010) explain how young people from a higher socio-economic background can delay adulthood by engaging with higher education and delaying other life course events, such as entering employment and childbearing, whereas young people from a lower socio-economic background have a more truncated childhood, entering the adult stage of their lives more quickly. These differences in the life course between more and less affluent young people may also have an impact on behaviours such as child-bearing, with individuals from a lower socio-economic background having children earlier compared to those from a higher socio-economic background as they are further along in the life course regardless of age.

These examples of how individuals experience of the life course may be dependent upon demographic factors, such as ethnicity and class, demonstrate how behaviours associated with different points in the life course vary between individuals. Life course theory therefore may not only provide a useful theoretical framework for understanding the processes associated with population change, but also how these processes vary across social groups. This is particularly important when taking into account the theories of social clustering and Habitus discussed earlier in this section. Should particular demographic groups, based upon ethnicity, class or other factors, cluster together within neighbourhoods, these differences between groups become more significant as the demographic profile of an area may result in differences in fertility, migration or mortality rates.

2.2.2:a) Urbanisation/Counter-Urbanisation

Within the life-course literature, other theories have emerged which can be used to explain population change and why particular areas may attract certain demographics at different stages in the life course. These theories have primarily been developed to understand some of the key patterns observed for migration, that have implications for local demography and demographic change.

Two key theories are urbanisation and counter-urbanisation. While during the industrial revolution, there was a trend towards urbanisation whereby individuals migrated from rural to urban areas for employment, in more recent times, this movement of people has been reversed in a trend defined as counter-urbanisation. Carr (1997:143) describes that the shift from urbanisation to counter-urbanisation "*can be measured by comparing the rate of population change for metropolitan areas against those for rural and non-metropolitan areas*". While urbanisation was triggered by the industrialisation process, where populations moved from rural, agricultural lifestyles to industrial work in the cities; the trend of counter-urbanisation has been driven by deindustrialisation and advances in technology which allow work to be carried out remotely. Newby (1989) explains this in Marsden et al (2005:2), arguing that "*For the first time since the industrial revolution, technological change is allowing rural areas to compete on an equal basis with towns and cities for employment".*

This observed trend of counter-urbanisation could therefore result in some areas growing at a greater rate than others, as migration flows from the cities into the countryside. Carr (1997) explains that there is some evidence of this, describing how, it was rural areas and small towns which experienced the greatest increase in population in England and Wales, with this trend of counter-urbanisation being observed across Western Europe and the USA. Even within rural areas, there may be some differences in growth rates, with Halfacree (2001) describing how counter-urbanisation is highly geographically and historically driven. In terms of geography, Halfacree (2001) explains how factors such as the housing market, employment opportunities, culture and accessibility all influence the nature of counter-urbanisation and the extent to which it occurs, while when examining the trend over time, the rate of counter-urbanisation occurring is uneven between areas based upon the local economy. These points made by Halfacree (2001) further highlight how trends in migration can vary between areas and result in uneven population growth.

Further to this, Halfacree (2001) explains that the counter-urbanisation does not only occur unevenly across space and time, but also does not occur evenly between social groups, with particular populations engaging with counter-urbanisation to a greater extent than others, with individuals from a higher socio-economic status more likely to engage with counter-urbanisation. Critiquing the counter-urbanisation theory, Halfacree (2001) explains that the concept focuses on the migration to rural areas but overlooks that there is continuing out-migration from rural to urban areas, warning that the character of an area may be changed as particular demographic groups leave rural areas and are replaced by another, for example younger school leavers leaving rural areas to find employment replaced by older couples retiring to the countryside.

2.2.2 b) Lifestyle Migration

This selective migration of particular groups can be understood using the theory of life style migration which is strongly linked to the life course and the theories of urbanisation and counter-urbanisation. Walford & Stockdale (2015) explain how selective migration occurs as individuals seek to obtain a better lifestyle either by moving (or being pushed) away from an area they are dissatisfied with or moving to (or being pulled) to an area which offers a better lifestyle. This theory can be linked to the life course theory as individual’s lifestyles changes throughout their lives (Walford & Stockdale, 2015). However, as noted previously by Halfacree (2001), lifestyle migration does not occur evenly across demographic groups can be understood as a class issue, with the relatively affluent middle-classes having a greater ability to migrate based upon lifestyle choices compared to poorer groups (Walford & Stockdale, 2015). This means that the concept of lifestyle migration can act as a useful framework through which to understand how residential mobility varies between social groups. Both class and age differences in counter-urbanisation and lifestyle migration may also result in demographics of an area being changed over time, resulting in differences in fertility and mortality rates between areas, impacting upon population size and structure.

This is an issue which has been addressed by Kulu and Washbrook (2014) who found that couples planning to have children tend to move from larger metropolitan areas to suburbs and smaller towns. This suggests that selective migration in couples preparing to have children may account for spatial differences in fertility rates. These findings also relate to the theory of counter-urbanisation to the life course theory, with migration being triggered by an individual's stage of life. In life course research, there have been links made between fertility and spatial mobility with fertility decisions also influencing migration decisions with Kulu (2006) describing how the birth of a child triggers 'residential relocations'. This suggests that fertility rates may be higher in some areas compared to others as particular communities may be considered more suitable for families at the stage of their life where they are considering having children. This is highlighted in the research by Bondi (1999) discussed earlier in this chapter, whereby young professional women were attracted to gentrified areas, but relocated when planning to have children.

As well as fertility rates, mortality rates have also been found to be impacted by selective migration. Norman et al (2005) suggest that selective migration also has an impact on differences in life expectancy at a local level, by reinforcing area deprivation. Selective migration impacts upon life expectancy and health when healthy people move from more deprived areas to less deprived areas. This results in a greater concentration of individuals with health issues in areas of deprivation, reducing the average life expectancy of that area. In addition to this, Norman et al (2005) further argue that the better health observed in the more affluent areas may also be reinforced by selective migration with less healthy individuals migrating to areas of deprivation. These comments by Norman et al (2005) therefore suggest that this relationship between selective migration, health and deprivation may account for the variation of life expectancy across small geographical areas.

These theories relating to migration are extremely significant when accounting for spatial difference in the growth rates between areas. One issue which may be particularly relevant to this research, is the role of age in triggering migration behaviour. Within a single area, lifestyle migration can account for an influx of older adults moving away from the cities to retire, and the outward migration of young adults into the cities seeking employment or further education. This results not only in uneven fertility and mortality rates between areas, but also spatial disparities in the age profiles of particular areas. As this thesis will explore a range of area characteristics and their impact upon the accuracy of small area population estimates and projections, this suggests that age is also an important demographic factor to consider, as areas with high proportions of particular age groups may be more prone to higher rates of error compared to others.

Overall, all the theories discussed within this section help to provide a framework through which to understand why populations may grow and develop unevenly. Through processes such as social clustering, selective migration and unequal rates of transition, it can be seen how populations grow at different rates or how the demographic composition of areas may change over time, impacting upon future growth. Based upon the theories discussed in this section and the examples given of the way in which demographic factors can influence population change; the relationship between characteristics of small areas and the performance of small area population estimates and projections is explored throughout this thesis.

As populations do not grow or change in a uniform way, it suggests that there will also be variation in the accuracy of the population estimates and projection which are used to capture this change. Taking into account the spatial unevenness in growth rates and the many factors which can influence how populations change, the analysis conducted in this thesis does not only explore the way in which accuracy varies but will also examine which area characteristics have the greatest impact upon error and whether specific areas are particularly vulnerable to higher rates of error.

2.3: DO SPATIAL DIFFERENCES MATTER?

Taking into account how populations grow and change unevenly is important, as it highlights the importance of small area population statistics in informing planning and decision making. Should populations grow by the same margin and at the same rate, population data for each small area would not be required, as national and sub-national projections would accurately capture changes across all areas. However, the literature discussed in the previous section, suggests that this is not the case, with differences in fertility, mortality and migration rates existing at a neighbourhood level. This section will therefore further explore the importance of small area population estimates and projections for capturing changes in the population at a local level and examining how these statistics are used.

2.3.1: Importance of Small Area Population Estimates and Projections

As discussed previously, small area population statistics are an important tool for capturing population change at a local level and accounting for differences in population change between communities. A review of the literature on the use of small area population estimates and projections reveals that these statistics are an increasingly important tool in the public, private and third sectors and are vital for informing planning and policy making. Understanding population change at a local level is important both in terms of population size and structure. While population data for small geographies are recorded in the census, this information can quickly become outdated, limiting its usefulness for informing planning and decision making (Udjo, 2016). It is therefore important that small area population estimates and projections are available for providing up-to-date local population statistics in the intercensal period.

As well as having knowledge of how many people live in an area, demographic factors such as age must be considered when planning future infrastructure and resources, with Ghosh and Rao (1994) explaining how small area population data is valuable when informing a range of tasks such as apportioning local government funding and city planning. When reflecting on why local population data for specific areas is more appropriate for carrying out these tasks compared to national data, Wardrop et al (2018:3530) explain that, *"human populations are not uniformly* *distributed within areal units and thus aggregate population data, particularly when only available for larger areas, do not accurately represent the true spatial distribution of the population".* For this reason, small area population statistics are required to ensure that resources are targeted effectively in the areas where they are most needed.

When describing the role of small area population statistics and their importance when making planning and policy decisions, Smith and Morrison (2005:761) explain that small area demographic analysis has three main goals; "*to advance knowledge, to inform public policy or to support business decision making".* Throughout this section, these goals will be explored in greater depth, examining cases where small area population statistics have been used to achieve these goals.

2.3.2: Advancing Knowledge

When considering the uses of small area population statistics, the first goal defined by Smith and Morrison (2005) concerns the advancement of knowledge. They explain that small areas are an important area of study when evaluating the impact of policies, in the epidemiology sector when examining differences in health outcomes and when examining local trends. When carrying out any research in small areas, population estimates are an important tool for providing up-to-date statistics to analyse local trends and compare areas. In many cases, these estimates are used as denominators when calculating secondary statistics such as mortality and unemployment rates (Wang & Li, 2017). By using population estimates in this way, it is possible to generate further information regarding the demographics of small areas and more closely study differences between communities.

When understanding the importance of small area population data in providing valuable knowledge to address local issues, Wardrop et al (2018) provide a powerful example of why accurate and current population data for small areas can be invaluable in the advancement of knowledge. In this study, Wardrop et al (2018) explain how emergency responders working in West Africa during the Ebola outbreak struggled to calculate local infection rates, as they did not have local population data to use as a denominator in their calculations. Having reliable population data for small areas was not only important for understanding the infection rate but also when providing aid, such as vaccines and treatments, as well as calculating recovery rates and the success of intervention. In order to understand both the prevalence of the disease in particular communities and develop knowledge of the size of the population at risk, small area estimates of the population were a vital tool. Overall, Wardrop et al (2018:3530) explain that in the international development sector, "*goals are based on ensuring that a certain percentage of the population has access to specific services or resources, or achieves a certain level of social, economic, or physical health. These measurements require a solid and regularly updated understanding of not only how many people live in a country, but where and who they are*".

2.3.3: Informing Public Policy

Both small area estimates and projections are widely used in public policy for informing a range of planning decisions relating to public services and health. Cai (2007:203) describe how local governments use these small area population statistics to, "*assess the needs for schools, parks, public transportation, and health-prevention programs, and to evaluate the impact of public policies*" among many other tasks. In the field of public policy, estimates and projections can be used in many different ways, from spatial analysis used for targeting infrastructure, such as school building in areas with growing young families, to being used as denominators when producing secondary statistics when comparing health disparities or employment levels across a community.

One example which highlights the role of small area population statistics can be found in Tayman et al's (1997) research, which examined the use of small area projections for planning locations for fire stations in San Diego County. They describe that small area population projections are an appropriate tool for this task, as when planning for services, a long term perspective is needed, as the needs and demands of the users change, based upon "*area dynamics and growth potential*" (Tayman et al (1997:203). Using population projections, this study identified areas where new fire stations may be needed in the future based upon changes in the population. By analysing the way in which the housing developments may impact upon the spread of the population in the future, Tayman et al (1997) described how it was possible to plan for the locations of new stations to ensure that the Fire Department's target of having 80% of critical sites within five minutes of a first responder's unit could be maintained in conjunction with changes in the population.

As well as using small area population projections for ensuring that public services meet the needs of the future population, small area population estimates are also an important tool for local governments. Pratesi and Salvati (2016) explain how policy makers need to know the 'situation' of an area at a local level to understand the impact their policies and interventions are having in different areas and to help stakeholders and citizens understand how policies are affecting their communities. In particular, Pratesi and Salvati (2016) describe how small area population estimates are particularly useful when measuring poverty in small areas. They explain that, although sample surveys covering income and living conditions are the main sources of statistical data for measuring poverty, these "*rarely provide credible estimates at a sub-regional and local level*" (Pratesi & Salvati, 2016:2). For this reason, they explain that small area estimates are of great importance when measuring poverty at a local level.

These examples demonstrate two ways in which small area population estimates and projections are used by local governments to inform public policy, both now and in the future. Wang and Li (2018) describe how small area population statistics are 'essential' as population size and distribution are key pieces of information when allocating funding and resources at a local level. They outline the wide array of public services which are planned and funded based upon small area population data such as public transport, sewage works and libraries. This emphasis on how important population data is for ensuring that local communities have the resources and infrastructure they need, highlights how important the accuracy of these statistics are, and therefore why it is important to acknowledge spatial differences in population change between small areas.

2.3.4: Business Decision Making

As well as having a role in the public sector, both small area population estimates and projections can be used in the private sector to aid business decision making, to maximise resources and profits. Smith and Morrison (2005) describe how in business demography, small area population statistics are invaluable to those making planning decisions. They explain that while small area demography and business demography are distinct fields of study, they are closely related. Issues such as the best areas to roll out an ethnic food line, target advertising of a particular product and where to introduce new transport routes, are all examples used to illustrate how small area estimates and projections are used in the commercial sector (Smith and Morrison, 2005).

A case study which illustrates how small area population estimates are used by the business community was presented by Morrison and Abrahamse (1996). In this example, a client wanted to find a location for a new supermarket, based upon a range of criteria related to the areas demographics. Demographic analysis was used to identify areas which contained particular populations, such as large families and two-income households, which could increase sales. Using population estimates and the requirements set out by the client, demographic data was used to identify ten areas within the region of interest in Southern California that would be the most suitable for attracting the clients target demographic and maximise profits.

In addition to targeting customers, small area population data is also valuable when recruiting staff. A study conducted by Thomas and Kirchner (1991) described a case where a fast food chain used demographic data to target recruiting events and advertising in local areas. In order to recruit employees with desirable characteristics, they first analysed the demographics of their most successful current staff members. Once the most desirable characteristics had been identified, advertising was targeted in local newspapers and through postal promotions in areas which contained high proportions of individuals from these desirable demographic groups.

Overall, the examples presented in this section demonstrate that population statistics for small areas have a range of uses and outline how they help to satisfy the needs of local planners and analysts who require population data between census years. Overall, Rayer (2015:162) summarises how widely small area population estimates and projections are used, explaining that; *“Population estimates and projections play a critical role in market analysis, facility planning, environmental planning, and the allocation of public and private funds. Estimates and projections for small areas, in particular, are used extensively in the public and private sectors, and demand for them has been growing”.* While this range of important issues which are informed by small area population estimates and projections make these statistics a worthwhile area of study in itself; Rayer's (2015) final point that the demand for this type of population data is increasing means that the evaluation of these statistics is increasingly relevant as small area estimates and projections become more prominent in planning processes. If these small area population statistics are being used more for informing the type of policy and planning decisions outlined in this section, it is vital that there is a greater understanding of their accuracy and the ways in which users understand these statistics along with their associated error.

2.4: CHALLENGES IN PRODUCING SMALL AREA POPULATION STATISTICS

While the previous section of this chapter explored the multitude of ways in which small area population estimates and projections are used, previous studies have found that they are difficult to produce and may provide unsatisfactory results (Hoque, 2012; Simpson et al, 1996; Rees et al, 2004). In this section, the challenges associated with producing small area population estimates and projections will be explored in order to build a greater understanding of why small area population statistics may be more vulnerable to error and what factors may contribute to these inaccuracies.

A review of the literature identifies three challenges associated with producing population statistics for small areas. Chi and Voss (2011) outline these three main challenges describing how producing population data for small areas can be difficult. The first of these challenges is concerned with the techniques used to produce small area population estimates and projections which may not be appropriate for producing population statistics at a local level. In particular, they highlight the Cohort Component method which uses age specific data regarding the components of population change (fertility, mortality and migration). While this data is easily accessible and reliable for larger, national and sub-national geographies, Chi and Voss (2011:506) suggest that for small geographical areas, this required data is *"too thin to support forecasts of this kind*".

As well as challenges associated with the availability of reliable data, Chi and Voss (2011) also explain than non-demographic factors such as land use restrictions or environmental constraints are generally not taken into account by methods for producing small area population statistics. They explain that, these non-demographic factors are often ignored as they are of a lower level of importance for larger areas compared to smaller geographies. Smith (1997) further develops the importance of environmental factors in developing small area demographic statistics, highlighting issues which may limit population growth in the future, such as current population densities and the capacity for an area to continue to grow in the future based upon government growth policies, and the availability of vacant land. This issue of non-demographic factors is considered to be particularly pertinent when taking into account the challenges associated with producing small area population statistics, with environmental factors understood to become more significant as the size of the areas of study decreases (Smith & Morrison, 2005). Smith (1997:190) explains that; *"In general, the smaller the area under consideration, the greater the potential impact of special events and growth constraints".*

The final explanation offered by Chi and Voss (2011) to explain why producing small area population statistics may be more challenging, concerns ‘neighbourhood effects’ which may influence population change and provide the context in which local demographic trends will occur. Smith and Morrison (2005) further explain this issue, describing how modest population changes in a small area such as the closing of a military base or the building or demolition of a housing complex will have a more significant impact on the population of a small area compared to a larger area. This again highlights the challenges associated with producing population statistics at a local level, as small changes in the population which may be missed in the methodology or assumptions used in the production of estimates or projections will result in a more significant error at a local level. This issue of ‘neighbourhood effects’ and the role of place in influencing population change will be a key theme of this thesis when exploring the performance of methods which produce population estimates and projections.

Overall, these challenges associated with producing accurate population estimates and projections is important to consider, as they may account for some of the variation in error between small areas. The issues highlighted by Chi and Voss (2011) such as limited land for housebuilding or neighbourhood effects are extremely area specific, with both the specific demographic and non-demographic factors unique to each small area. This may mean that the accuracy of small area population estimates and projections will vary based upon the specific challenges associated with each area, with it proving more difficult to produce accurate estimates or projection for some areas compared to others. Therefore, some of the challenges cited by Chi and Voss (2011) have helped to inform this current research. In particular, the issue of non-demographic factors and the consideration of physical, geographical and policy restraints which may restrict population growth, may be especially relevant when using Scotland as a study area. As there are a number of small areas which combine island populations or in some cases cover both island and mainland geographies, as well as recent issues regarding stress on housing stock due to the increase in unregulated Airbnb lets (Rae, 2018; Evans et al, 2019), this issue of non-demographic factors may be of particular interest in Scotland. For this reason, issues regarding how local users of population statistics feel that the non-demographic factors, which exist in their areas impact upon the population statistics, produced for these geographies, will be explored in the qualitative analysis chapter (Chapter 7).

2.5: CONCLUSION

Overall, this chapter has explored the key academic and theoretical ideas which currently exist in the literature, which may help to explain how population change may occur unevenly across all areas, and the way in which this may impact upon the accuracy of small area population estimates and projections. A review of all the literature discussed in this research highlights, that despite accurate small area population statistics being of great and growing importance for planners and policy makers, there are many challenges which make producing consistently accurate small area population statistics difficult, from differences in growth rates to non-demographic issues outlined by Chi and Voss (2011). Gathering knowledge regarding how behaviours and decision making varies across demographic groups, as well as how these groups are dispersed, can help provide more information about how populations in these areas may be expected to change. As this variation in accuracy between areas will be a key focus for this thesis, the previous research and key theories outlined in this chapter help to explain why any variation may be expected, particularly when dealing with small areas. This literature review has therefore identified particular demographic factors such as age, socio-economic status and ethnicity which may have a particular impact on the accuracy of small area estimates and projections and has informed the analysis conducted in this thesis when examining which area characteristics impact upon error. In addition to this, results of this review have highlighted that one single method may not be the most effective for all area types, but rather that some methods may be better suited to particular areas compared to others. This is an issue which will be explored further throughout this thesis. Taking into account the issues which contribute to the demographic differences in population change, may also help when interpreting the results of this research, should they indicate that areas with particular characteristics are more accurate compared to others.

While this chapter has examined to what extent demographic factors and social behaviours impact upon population change and how in turn this could affect the accuracy of small area population estimates and projections between areas; these demographic issues are not the only factors which can have an effect upon the accuracy of these small area statistics. As well as examining how area characteristics may influence the accuracy of population statistics for small areas, this thesis also aims to examine how different methodologies for producing these estimates and projections may perform differently from one another and, in particular whether a single method can prove the most accurate across all small areas in Scotland. For this reason, a separate review of the literature concerning the key methods which have been developed to produce small area estimates and projections will be carried out in the following chapter.

Chapter 3: Review of Methods

3.1: INTRODUCTION

As well as understanding the issues which may result in differences in how population change may occur unevenly across different area types or the way in which demographic factors may influence the fertility, mortality and migration of individuals, it is also important to understand the range of methods which are available to measure this population change. Over the years, demographers have developed a wide range of methods and models for producing population estimates and projections, with various levels of detail and mathematical complexity. Swanson and Tayman (2012:1) describe how the methodological development of population estimates "*only really took off in the late 1930s and early 1940s, fuelled in large part by the need for low-cost and timely information, generated by the great depression and World War II".* The methods which have been developed over this period for producing both population estimates and projections will be explored in this chapter, examining the way in which these methods have been evaluated in previous research. The focus of this chapter is to explore the performance of methods which are commonly used by statistical agencies and simpler methods which may provide an alternative, more accessible approach for producing small area population statistics. Following this review of available methods, the data and processes used to apply each approach included in this research will be discussed in further detail in Chapter 4.

This chapter will be structured into five sections, each exploring a different aspect of the way in which demographers currently view the range of approaches which are available for producing population estimates and projections and explore the current research which exists to evaluate these methods. The first section will address the differences between estimates and projections, and how there are some similarities in the methods used to produce them. Following this, in the second section, the Cohort Component method which is currently used for producing both estimates and projections in Scotland will be examined. The range of alternative methods to the Cohort Component method will also be explored in the third section before section four outlines the rationale behind the methods chosen by statistical agencies within the UK. The fifth and final section will then explore how these methods can be categorised into simple and complex methods and how these categorisations have been developed. Overall, through each of these sections, this chapter seeks to explore the body of research which exists, exploring the range of methods which have been developed to produce population estimates and projections, and how this previous research can help to inform the research conducted in this thesis.

3.2: ESTIMATES AND PROJECTIONS: AIMS AND DIFFERENCES

Before reviewing the previous literature which has outlined the range of available methods for producing population estimates and projections, it is important to understand how these statistics differ in their aims.

While both population estimates and projections provide important data regarding the population size and structure, as discussed in the previous section, they differ in the information they provide. Population estimates provide an approximation of the population size for the present by updating past census or estimate data based upon population change which had occurred since the previous year. Conversely, population projections show what the future population size and structure would be based upon the assumption that historical changes in the population continued into the future. Rayer (2015) explains that population estimates and projections are distinct both in terms of the time period they provide information for, but also in the data used. When summarising the difference in how the data is used for producing estimates and projections, Rayer (2015:162) states that; "si*nce projections refer to the size of the population at a future point in time, they cannot be based on actual data comprising the components of population change; rather, they must be based on the extension of either current or expected population trends into the future*".

Although population estimates and projections are two distinct categories of population statistics, they do share some similarities, in particular, the methods used to produce them. While there are some methods which are best suited for either estimates or projections, there are methods which can be used in the production of both, with these methods applied in similar ways. The main example of a shared method is the Cohort Component approach, which uses the components of population change (fertility, mortality and migration) to update the past population. In Scotland, this method is used in the production of both population estimates and projections. In this chapter, a range of methods for producing population estimates and projections will be explored in greater detail, focusing particularly on how well suited each method is for producing small area estimates/projections.

3.3: DOMINANCE OF THE COHORT COMPONENT METHOD

Despite the range of available methods which exist for producing population estimates and projections, the Cohort Component method appears to have emerged as the dominant approach in this field, becoming almost the default method in many cases. This is highlighted by Skirbekk et al (2008) who outline how commonly used this method is, with the UN, Eurostat and 'most national statistical bureaus' using this Cohort Component method. When describing how prolific the Cohort Component method is in the field of demography, Rayer (2008:15) describes this method as the "*de-facto standard, even for small areas*". As well as its dominance, the Cohort Component method is of particular interest in this research, as it is the method currently used by NRS for producing both small area population estimates and projections in Scotland.

Based upon the demographic balancing equation, the Cohort Component method uses birth, death and migration data to update the past population in order to produce estimates and projections (Swanson & Tayman, 2012). Using the census as the starting point, the process of applying this method involves adding the births which have occurred in the intervening period, subtracting the number of deaths and finally adding the net migration figures, and in some cases an additional step will be included to account for special population groups such as the armed forces, prisoners and students (ONS, 2019). This inclusion of each element of population change (births, deaths and migration) is one of the reasons why Swanson and Tayman (2012:110) believe that the Cohort Component method is so popular, as it "*can provide a more complete explanation of the reasons behind the population change than other estimation techniques*". Furthermore, Swanson and Tayman (2012) describe the many other advantages of the Cohort Component method over alternative approaches. They explain that this method can be applied for any level of geography where data is available and can provide highly detailed statistics using disaggregated data to produce estimates and projections including for a range of population characteristics such as sex, age and ethnicity.

As this method is commonly used and widely favoured by a range of high profile organisations from the UN to national governments, it is important to acknowledge some of the challenges associated with this approach, particularly for small areas. While the Cohort Component method is considered to be a robust approach for producing population estimates and projections for larger areas such as nations, states or counties, it is more difficult to apply to small areas. While the Cohort Component method is suitable for any type of geography, there are some challenges when applying this method to small areas. The main difficulty facing demographers using this approach for producing local population estimates and projections is data availability, in particular data regarding migration in and out of these small areas. Rees et al (2004) explain that, while birth and death data is generally available, it is rare to find reliable migration data for small local areas.

As well as issues regarding data availability, Smith (1986) explains that migration is also the most difficult element of population change to accurately incorporate into population projections for small areas. They explain that, while trends in fertility and mortality generally change slowly over time, migration can be volatile, particularly in small areas. Further to this, Smith et al (2013) explain how migration is the primary driver of population change at a local level, as it has a greater impact for small areas compared to a regional and national level, making migration the major source of uncertainty in small area population projections produced using the Cohort Component method.

While Swanson and Tayman (2012) described the use of the individual drivers of population change as one of the strengths of the Cohort Component method, as it allows analysts to understand the factors which are driving population change in each area; it is also this individual processing of each element of population change which could leave it vulnerable to inaccuracies or inconsistencies. With some data required more difficult to obtain for small areas, and local populations more volatile and susceptible to change, the Cohort Component method could be seen as particularly susceptible to error when dealing with small areas. The issues discussed in this section, particularly regarding the challenges associated with accounting for migration and the impact this may have on the accuracy of estimates and projections produced using the Cohort Component method will be explored further in this research.

3.4: ALTERNATIVE METHODS

Although the Cohort Component method is the approach currently used in Scotland for producing small area population estimates and projections, there are a wide range of alternative methods which exist, but differ in both the amount of data and skill required to apply the them, and the level of detail they provide. In order to understand this range of methods and explore their place in the field of applied demography, they will be explored in greater detail. The examination of alternative methods in this section will examine the rationale behind each of these methods, their strengths and weaknesses, as well as how suitable they are for small areas. This section will be structured using the broad categories of estimation and projection methods as identified by George et al (2004) and Swanson and Tayman (2012) respectively. The definitions of these categories can be found in Table 3.1 below. As the Cohort Component method has been discussed in the previous section (3.3), the methods covered in this section will focus on the alternative methods.

Table 3.1: Method Categories

	Method Types	**Examples**
Population Estimates	Ratio Methods	• Shift Share • Constant Share • Share-of-Growth
	Symptomatic Methods	• Housing Unit • Censal-Ratio
	Regression Methods	• Ratio Correlation (Simple Version used by ONS) • Difference Correlation • Average Correlation
	Sample Methods	• Structure Preserving Estimation Methodology (SPREE). • Synthetic Methods
Population Projections	Structural Methods	• Urban Systems Models • Economic-Demographic Models
Both Estimates and Projections	(Trend) Extrapolation	• Linear/Arithmetic Models • Geometric Model • Exponential Model
	Component Methods	• Cohort Component (Used by NRS) • Hamilton Perry Method

(Source: Swanson & Tayman, 2012)

3.4.1: Extrapolation and Trend Based Extrapolation Methods

These two Extrapolation methods share the same underlying theory, that changes in the population observed in the past will continue into the future (Swanson & Tayman, 2012, George et al, 2004). Rayer (2004:1) explains that despite the 'ascendancy' of the Cohort Component method, simple Extrapolation methods "*remain popular, especially for small areas, where their ease of use, small data requirements, and reliability often compare favourably with more complex projection models*". While there are many different sub-categories under the umbrella of Extrapolation methods, such as linear or geometric growth, they are all mathematical approaches which only require two data points (launch year and base year). As a result, these methods are popular due to their low cost and are less data intensive compared to other methods (Thatkar et al, 2018).

While there are many advantages associated with the Extrapolation methods such as ease and costs of application, George et al (2004) explain that there are some shortcomings associated with these methods. They explain that these approaches provide very limited information regarding disaggregated, and detailed population characteristics, for example single year of age or ethnicity, and, unlike the Cohort Component method, do not take into account the components of population change. As a result, George et al (2004) explain that exponential methods cannot effectively account for the factors which are driving population change in an area, unlike the Cohort Component method; nor allow analysts to adjust elements of population change or alter assumptions to create speculative projection scenarios for a range of variant projections. When considering using these Extrapolation methods for producing population estimates, Shryock et al (1980) explain that it is important to take these limitations into account, particularly when producing estimates by age. They explain that *"the assumption that the direction and average amount of population change by age in a past intercensal period will continue for another intercensal period is subject to considerable error. We should therefore, expect such methods to be less accurate than the cohort component method"* (Shryock et al, 1980:742).

While there appears to be a view, as expressed by Shryock et al, 1980), that population statistics produced using Extrapolation methods are considered to be less accurate when compared to the Cohort Component method, there is some empirical evidence which challenges this stand point. When comparing the population projections for small areas over a seven-year projection period produced using the Cohort Component method to those from Extrapolation methods, Stoto, 1983 found that the Geometric, Extrapolation method outperformed the Cohort Component when producing projections for the total population Further research comparing these methods supported these findings, with Rayer (2008:423) explaining that *"there have been numerous studies (Ascher 1978; Isserman 1977; Long 1995; Murdock et al. 1984; Smith and Sincich 1992; Stoto 1983) which have demonstrated that complex models* [including the Cohort Component method] *are no more accurate than trend Extrapolation techniques for total populations".* Although these studies suggest that there is some evidence that these Extrapolation methods may be at least as accurate, if not more so, than more complex and data intensive methods such as the

Cohort Component method, these studies generally focus on total population estimates for sub-national areas while small area, age-specific projections have been largely over-looked. As this project focuses on the performance of small area projections, the accuracy of these Extrapolation methods at a local level, with age detail, will be addressed in this thesis in response to this gap in the literature.

3.4.2 Structural Methods

The third category of population projections, are Structural Model methods. Wang and Shi (2016) explain that, in these models, population change is understood through its relationship with one or more explanatory variables, usually focusing on migration or economics. They further identify two main types of these models; Economic-Demographic and Urban Systems models. In general, these models can be described as a process of projecting future population trends using a projection of socio-economic indicators (O'Neill et al, 2001). Commonly these models are used to project trends in the components of population growth, such as projecting future migration based upon supply and demand for labour (Smith & Sincich, 1992). The most commonly used Structural method for producing population projections for small areas is the Urban Systems method. Smith et al (2013) describe how the main features of this method is the connection of land use, transportation and activity location. Understanding these factors and how they are connected is then used to anticipate changes in the population, based upon the potential for residential development and other factors.

While these structural models have become more popular in recent years (Smith et al, 2013), George et al (2004) explain that due to the extensive amount of data required and the difficulties associated with their application compared to both Cohort and Extrapolation methods, these structural methods are 'only accessible to a narrow range of practitioners' and so are not included in this research.

3.4.3: Ratio Methods

Ratio or Ratio Extrapolation methods are another approach which can be used in the production of both population estimates and projections. In these methods, the population of a small area is estimated or projected based upon the change in population for the larger area which the small area is nested within, for example estimating the county population based upon changes observed in the national population (Carmichael, 2016). The underlying theory of this method is that population change in the smaller area will mirror the change observed for the larger area, as the same local factors will affect both geographies (Chaplin & Diaz-Venegas, 2007). Like the Extrapolation methods discussed previously, these Ratio methods are considered to be a simple approach to producing population statistics, requiring minimal data and are considered easy to apply (Swanson & Tayman, 2012).

While the simplicity of these Ratio methods may make them desirable to users, previous research has also uncovered some limitations of these methods. A study conducted by Hachadoorian et al (2011) compared three types of Ratio methods (the Constant Share, Shift Share and Share-of Growth methods) to the official population estimates produced by the US Census Bureau for US states. In this research, Hachadoorian et al (2011) identified a number of issues associated with this method which they described as 'validity problems'. The main problems uncovered in this study were a tendency for these ratio methods to produce negative populations or for them to undergo a process termed 'trend reversal', whereby projections indicated the opposite direction of growth to that observed.

While this research deals with the use of Ratio methods for producing population projections, there appears to be little previous research into how these methods perform for population estimates, particularly for sub-council areas. For this reason, Ratio methods will be included in this thesis. By evaluating Ratio methods as part of this project, it does not only address this gap in the literature, but also provides an opportunity to more closely examine the effect of spatial variation on estimate error. As discussed in the previous chapter, there are many ways in which population growth can differ at a local level. Should these Ratio methods, which assume small areas change at the same rate as their parent area, prove effective in producing reasonably accurate small area estimates, it may suggest that local variation in population growth has little effect on estimate accuracy.

3.4.4: Symptomatic Methods

Another type of method used to produce population estimates identified by Swanson and Tayman (2012) is the Symptomatic method. Methods which can be defined as symptomatic have been used by statistical agencies, for example the Ratio Change method used by the ONS in England and Wales. These approaches use indicators of the population to produce population statistics. Rayer (2015) explains that there are two types of data which can be used to produce population estimates and projections; direct and indirect data. Direct data refers to formal measures of the population such as that found in the census or administrative records, while indirect data refers to information which is 'symptomatic' of the population being estimated. Examples of these symptomatic, indirect sources of data include school enrolments, tax records and electoral data (Rayer, 2015). Symptomatic methods of producing population statistics are based upon the assumption that changes in the indirect sources of population data over a given period can act as an indicator for changes in the population as a whole (Ericksen, 1973). There are several types of estimation methods which can be classed as Symptomatic methods, with Swanson & Tayman (2012) identifying the Housing Unit method and Censal Ratio Method as the most commonly used approaches of this type.

In previous research which has explored the use of administrative, symptomatic indicators of the population in the production of population estimates, the usefulness of these types of symptomatic approaches have been discussed. One such analysis conducted by Palit et al (1984) explains the benefits and challenges of using administrative indicators such as drivers licence and tax returns to produce population estimates. Palit et al (1984:577) describe how administrative data is only useful in population estimation if they are '*symptomatic of the presence or absence of population'*. In short, this means that administrative data sets used as an indicator of the population size must include counts of the number of people present in the administrative data set, and the changes in the counts of these individuals must change in a manner which reflects changes in the population as a whole, with Palit et al (1984) explaining that some data sets are more weakly linked to population movements compared to others. One of the main challenges associated with using this type of symptomatic data is differences in the culture and behaviour of the population between areas, with attitudes associated with engaging with particular data sets varying between places. As well as differences between area, Palit et al (1984) also explain that the usefulness of a particular data set as an indicator of the population may change. In this evaluation, they describe how changes in the law or in public policy, or changing attitudes of the public may make some sources of data less useful over time. Finally, Palit et al (1984: 578) express concern that administrative data sets may contain data which is inaccurate, due to lags in updating the information recorded in the data sets. They explain that; "*administrative data sets do not record a change in a person's status until this change is registered. The recorded values for symptomatic data will therefore lag behind its true value. Persons moving from one area to another for example may take considerable time to change their address with the appropriate agency".*

These issues discussed by Palit et al (1984) explain many of the challenges which may be associated with using administrative datasets as an indicator of the total population in the production of population estimates. Despite these challenges, there have been many projects which have used symptomatic methods such as the censal indicator method to produce estimates. However, in many cases, such as in the research conducted by Smith and Nogle (2004), which compared methods for producing estimates of the Hispanic population of Florida, birth and death data were used as symptomatic indicators. Swanson and Tayman (2012) explain that an early version of Symptomatic methods was the Vital Rates method developed by Bogue (1950) which used birth and death rates, with development in the 1970s incorporating alternative symptomatic indicators into the process. While there have been several studies which have evaluated the Symptomatic methods which feature vital statistics data to support the administrative indicators of population change (Smith & Nogle, 2004; Brown, 1955; Ericksen, 1973), there has been little focus on evaluating estimates which have been produced using administrative or indicator data as the sole source of population information used in the estimation process, and how well these datasets capture changes in the populations. As the Ratio Change method, a Symptomatic approach, is used by statistical agencies, such as the ONS, this use of Symptomatic data in the production of small area population estimates will be examined further in this study.

3.4.5: Sample Methods

When defining the main approaches used to produce population estimates, Swanson and Tayman (2012) include Sample methods which are defined as Synthetic and SPREE (Structure Preserving Estimation Methodology) methods. While these methods are included by Swanson and Tayman (2012) as estimation methods, they note that these methods are seldom used to estimate the features of a population such as age, sex or ethnicity; and are even less likely to be used to estimate the total population. Instead, these methods are typically used to estimate proportions of a sub-set or sample of the population, such as those who are unemployed, and are more commonly used by survey statisticians. While it is important to recognise that these sample methods can be used to produce small area population estimates and projections; as with the Structural methods discussed previously, these Sample methods do not fit within the scope of this study due to their focus on estimating sub-groups within the population rather than being used by agencies to produce their official population estimates. Sample methods will not be explored further in this study.

3.4.6: Regression Methods

The final type of method which will be discussed in this chapter is the Regression method for producing population estimates. Swanson and Tayman (2015) describe how the most commonly used Regression method is the Ratio Correlation method developed by Schmitt and Crosetti (1954), while Rayer (2015) describes how some methods such as the Apportionment, Ratio change and Additive change methods can be considered to be simpler versions of the Ratio-Correlation approach, with these approaches routinely used by statistics agencies (Simpson et al ,1996). The Ratio-Correlation method involves a two-step process whereby a multiple regression model is developed using symptomatic indicators of the population as the independent variables, and the population data (typically derived from two census years) as the dependent variable. This is a two-step process whereby the regression model is developed and then implemented to produce the population estimate (Swanson & Tayman, 2015). Swanson and Tedrow (1984:374) describe how the main aim of this method is to *"estimate the temporal change in county population proportions using (observed) temporal changes in county proportions of symptomatic indicators … The temporal change is measured simply by taking a ratio of the proportions at two points in time for each variable; hence the name ratio-correlation".*

There have been many studies conducted evaluating the performance of the Ratio Correlation method, both in isolation, as well as in comparison with other methods discussed in this section. One of these studies was conducted by Goldberg et al (1964). In this research, the Ratio Correlation method was compared to a series of complex methods for counties in Michigan, USA, building upon the work of Schmitt and Crosetti (1954) which was conducted when the method was first developed. The results of this research by Goldberg (1964) found a statistically significant difference between the Ratio Correlation method and the other methods tested in this study, with the Ratio Correlation method outperforming the three other methods, all of which were Symptomatic Indicator methods.

As well as the comparison to other approaches, the limitations of this method have also been well documented, with Swanson and Tayman (2015) outlining the key sources of uncertainty in estimates produced using these Regression methods. One criticism of this method highlighted by Swanson and Tayman (2015) is that, the performance of the regression methods relies upon how they are applied and the judgement of the analyst. In the case of Regression methods, including the Ratio Correlation method, the accuracy of the method is dependent on the variables chosen, and whether the data sets used are reliable and have consistent coverage of the population (Swanson & Tayman, 2015). In addition to issues in choosing the variables to be included in the model, concerns were also raised that the use of multiple variables to produce population estimates made it challenging to 'decompose' any error, making it difficult to understand how inaccuracies in population estimates produced using these methods occurred. However, Swanson and Tayman (2015) explain that this issue of not being able to decompose the error is not a problem which is unique to Regression methods, but is an issue for all methods which do not use the components of change in their formulation.

While these regression approaches are widely used and are seen to produce reliable estimates, mostly for the total population (Swanson and Tayman, 2012), these methods require a great amount of data and can be seen as requiring a greater level of skill compared to some other methods discussed in this chapter. Despite this, some simplified versions of this ratio-correlation method identified by Rayer (2015), do provide an opportunity to explore regression methods, as most commonly employed by statistical agencies. In particular, this research will focus on the Ratio Change method which is currently used by ONS in England and Wales.

3.5: METHODS THROUGHOUT THE UK

One example of the range of methods which are used, can be seen within the UK, where each of the national statistical agencies for Scotland, England and Wales, and Northern Ireland (NRS, ONS and NISRA) each use a different method for producing their official small area population estimates (ONS, 2019). While all these agencies use the Cohort Component method to produce their national and sub-national population estimates (ONS, 2019; NRS, 2018; NISRA, 2016), when producing their sub-council level population estimates, each of these agencies use different approaches.

Table 3.2: Summary of methods used to produce population statistics by producer body, at July 2015

Product	ONS	Wales	NRS	NISRA
National Mid-Year Population Estimates	Cohort Component	Cohort Component	Cohort Component	Cohort Component
Subnational Mid-Year Population Estimates	Cohort Component (except for CCGs, which use Ratio Change)	Cohort Component	Cohort Component	Mixed Cohort Component and Ratio Change
Population Estimates for Small Geographic Areas	Ratio Change	Ratio Change	Cohort Component	Mixed Cohort Component and Ratio Change

(Adapted from table available from UK Statistics Authority, 2015:6)

3.5.1: Estimation Methods in Scotland

In Scotland, the Cohort Component method is used to produce population estimates and projections for all geographies. While initial small area population estimates were produced using the Apportionment method, based upon the Community Health Index (CHI), for ward-level estimates in 1999, a review of these estimates indicated that these were less satisfactory compared to those produced using the Cohort Component method which was subsequently adopted as the preferred method (NRS, 2020). As well as producing more satisfactory results, National Records of Scotland (2015) explain that the Cohort Component method is used as it is considered to be a standard demographic method and is widely used by other statistical agencies. Discussed previously in this chapter, the Cohort Component method is considered useful as it can be applied to any geographical area, and allows users to analyse the factors which are driving changes in the population, by processing fertility, mortality and migration data separately.

3.5.2: Estimation Methods in England and Wales

While NRS uses a consistent method for producing all population estimates, when producing small area population estimates in England and Wales, ONS favour the Ratio-Change method over the Cohort Component method which is used to produce their estimates for higher levels of geography. When selecting a method for producing their small area population estimates, the ONS developed a shortlist of the Cohort Component, Ratio Change and Apportionment methods. As in Scotland, the Apportionment method was found to produce unsatisfactory results, with poorer estimates produced using this method compared to the Cohort Component and Ratio Change methods (Bates, 2006). When describing why the Ratio Change method was chosen, Bates (2006) explains that this Ratio Change approach more closely adhered to the criteria developed by ONS to identify a preferred method.

3.5.3: Estimation Methods in Northern Ireland

As in England and Wales, Northern Ireland also uses the Cohort Component method to produce their national population estimates, but adopt an alternative method for producing estimates at a sub-national and local level. In this case, the Northern Irish Statistics and Research Agency employ a mixed methods approach whereby two sets of estimates are produced (one set using the Cohort Component method and another using the Ratio Change method) and the average of these two approaches is used as the estimate (UK Statistics Authority, 2015). Dignan, et al (2010) explain the rationale behind this approach, describing how using a mixed approach not only utilises the strengths of both methods, but also makes full use of available data and overcomes some of the limitations with each single method. While the Cohort Component method is used by NISRA at national level, Dignan et al (2010) explain that the Cohort Component method is not used for producing small area population estimates in Northern Ireland due to challenges in gathering reliable migration data. The Ratio Change method was also discounted as a potential method, with Dignan et al (2010) explaining that population change experienced in Northern Ireland between 2001 and 2008 and that the relationship between the proxy population indicators and true population would weaken in the years furthest from the census. As a result of these limitations, a mixed approach was seen as the most appropriate for use in Northern Ireland, both to overcome each methods' shortcomings and to enhance their strengths.

This use of three different methods employed by each of the statistical agencies within the UK, along with the justification of why each approach was chosen highlights the wide range of issues which influence decision making when selecting methods. These include the prominence of particular methods, reliability of the data required and the complexity of the process. It is this use of the differences in the methods chosen by these UK statistical agencies which has informed some aspects of this research. While, there has been some research carried out which has compared estimates produced by the Ratio Change and Cohort Component methods, such as Snowling (2008) for Scotland and Dignan et al (2008) in Northern Ireland, these projects have simply compared the estimates produced by each of these methods to one another, rather than evaluating their accuracy. Although both of these studies found that the Cohort Component method and the Ratio Change method both produced similar estimates and concluded that these results indicated that these approaches performed to a similar standard, there has been no previous research conducted to measure how precise each of these methods are when compared to the true population. Bates (2006) writes that "*Unfortunately there are no benchmark or gold standard estimates nationally that can be used to measure the* *accuracy of these estimates”*. However, since these research projects took place, the release of the 2011 census figures have provided a reliable ‘population truth’ for comparison. This means that the quality assurance suggestion made by Dignan et al (2008:19) that a measure of accuracy would “*require a benchmark such as the Census of Population”*, is now possible. This exposes a gap in the current research which can be addressed in this thesis, where the accuracy of each of the three methods used by UK statistical agencies will be explored for small areas in Scotland.

3.5.4: Projection Methods in the UK

While there are a range of methods used to produce small area population estimates by different statistical agencies in the UK, as Scotland is the first to produce population projections at a sub-council level, the Cohort Component method is the only method used for producing this type of projection in the UK. Due to the absence of sub-council population projections elsewhere in the UK, the Cohort Component method will therefore only be compared to simple methods. This categorisation of methods as either simple or complex will be explored further in the following section.

3.6: DEFINING SIMPLE AND COMPLEX METHODS

One of the issues which will be explored in this thesis will be comparing the methods for producing population estimates and projections which are employed by statistical agencies in the UK, to simpler methods which could prove less data and labour intensive. This project will therefore frame this evaluation of methods as a comparison of complex and simple methods. In order to explore these categories of methods further, previous research which has examined simple and complex methods for producing population statistics will be explored in this section.

In existing literature concerning population projections, there have been several papers which have the described methods for producing these statistics as either simple or complex. Smith and Sincich (1992) describe how methods cannot only be defined as either simple or complex, but also as either sophisticated or naïve. When discussing the difference between sophisticated and naïve techniques, Smith and Sincich (1992) explain that naïve methods produce projections which are solely based upon past population values and trends, whereas sophisticated techniques are models in which population change is seen as a function of changes in economic or other variables. As this project deals with evaluating population projections in Scotland which aim to demonstrate what the future population would be if past trends continued, all the projection methods in this project will be naïve; however, within this category of methods, approaches can still be defined as simple or complex.

One study which has examined simple and complex methods was conducted by Smith (1997) and clearly defines each of these terms. In this paper, while Smith (1997) explains that there is no official definition of either simple nor complex projection methods, it is acknowledged that there does appear to be a consensus amongst researchers whereby *“linear and exponential Extrapolations are generally* *classified as simple, whereas cohort-component and ARIMA time series models are generally classified as complex"* (Smith, 1997:558). While Smith (1997) gives this straightforward definition of what methods are generally considered to be simple or complex, Smith et al (2013) explains that this classification of methods should not be seen as dichotomous categories with methods defined as simple or complex, but rather as a continuum, where methods are seen as either more complex or more simple compared to other methods based upon the level of skill required. Using this concept of a spectrum of complexity or simplicity, Smith et al (2013) define a range of methods, categorising them as Simple, More Complex and Most Complex. In their description of simple methods, as in the research previously discussed by Smith (1997), Smith et al (2013) include linear and Extrapolation methods, as well as share methods such as Constant-Share and Share of Growth models. These methods are described as simple as they require only a small amount of input data and can be produced with a limited skill level. More Complex methods are seen as regression or time series (ARIMA) methods. Smith et al (2013) consider these methods to be more complex compared to the 'Simple' methods as they require more data and a greater level of skill, however, they require highly aggregated data and do not take in to account the effects of other variables. Finally, Smith et al (2013), define the Most Complex methods, these approaches are considered to be of greater complexity than both the Simple and More Complex methods as they require a greater level of mathematical skill to apply, and use a substantial amount of data. Using this criteria, methods such as the Cohort Component, Structural and Microsimulation methods are all considered to be the 'Most Complex'.

From this categorisation of methods developed by Smith et al (2013), methods can be identified as having different levels of complexity or simplicity and informs the methods chosen for evaluation in this research. While in previous research it is primarily projection methods which are categorised in terms of complexity, as many projection methods can also be used to produce population estimates, it would be reasonable to extend this categorisation of methods to population estimates. As this thesis aims to evaluate the small area population estimates and projections in Scotland, the Cohort Component method which is currently used and is regarded as one of the most complex methods, will be compared to methods which are considered to be the simplest, as identified by Smith et al (2013). By exploring how well these simple methods perform in comparison to a complex method such as the Cohort Component method, it may give an indication of how useful these simple methods could be for empowering organisations and agencies, who may have less access to the skills and resources held by national statistical agencies, to produce their own population statistics should they desire to do so.

3.7: CONCLUSION

The aim of this chapter was to review the range of methods which have been developed to produce both population estimates and projections for small areas. In particular, this chapter focused on approaches employed by the UK National statistical agencies, as well as simpler strategies that might be undertaken by local planners. As well as identifying the key methods, this review of the existing literature has also helped to develop a greater understanding the frameworks which have been developed by demographers to organise and categorise these approaches. This review of the previous research has exposed some gaps in the current literature which could be addressed in this thesis. In particular, this project appears to provide a clear opportunity to explore the use of different methods within the UK, building on the work of Snowling (2008) to quantify the level of error found in estimates produced by the Cohort Component and Ratio Change methods for small areas in Scotland. In addition to building on previous research which has focused on methods used in the UK, this research can also develop previous research which has compared simple methods to the Cohort Component method. By examining these simple methods for producing both population estimates and projections, this research will evaluate the extent to which simple methods might allow less experienced or skilled analysts to produce their own small area population statistics to a satisfactory standard. All the methods which will be included in this research, along with the data and processes required to apply these methods will be outlined in Chapter 4.

Chapter 4: Methodology and Data Chapter

4.1: INTRODUCTION

The aims of this thesis are to evaluate the accuracy of sub-council population estimates and projections in Scotland focussing on methods used by National Statistical agencies and those simpler methods that may be applied using fewer resources. This thesis will examine how the variation in the accuracy of these small area statistics are linked to place, age and method, and how local analysts use and engage with these demographic statistics. Informed by the research discussed in the previous literature reviews, this chapter will outline the data and methodology used to conduct this evaluation and comparison of methods.

This chapter will describe the methods used to achieve these aims and a set of corresponding research questions which emerge from the previous reviews of the literature. In this chapter, the research questions will first be defined, before discussing the theoretical underpinnings of the methodology applied in this thesis and the outline of the process and data required to conduct the quantitative and qualitative analysis conducted in this research.

4.2: RESEARCH QUESTIONS

This project will be structured with three analysis chapters which will deal with the following research questions in the Scottish context:

1. Does the Cohort Component method produce more accurate population estimates and projections for small areas compared to alternative methods?

2. To what extent do demographic factors such as place and age influence the accuracy of small area population estimates and projections?

3. How do users engage with small area estimates and projections, in particular, the uncertainty which is associated with such statistics?

4.3: THEORETICAL UNDERPINNINGS

Prior to developing the methodology used to conduct the analysis carried out in this thesis, it is important to understand the theoretical underpinnings which provide a framework for this project and ground it within the field of demography. A term first coined in 1855 by the statistician Achille Guillard, the word demography translates from Greek meaning "*Description of the people*" (Rowland, 2003:16). The scientific field of demography is defined as "*the study of human population in terms of size, growth, movement and other variables*" (Calhoun, 2002:115) or "*the quantitative* *study of human populations*" (Reading, 1996:61). This description goes some way to describe this research project, using statistical analysis to evaluate the accuracy of Scotland's small area population estimates and projections. While this research can be clearly defined as rooted in demography, since the field was first defined by Guillard, there have been many developments, with different branches emerging.

4.3.1: Applied Demography

With its focus on methodology and quantifying accuracy, this project features many of the characteristics which fall under the branch of demography referred to as Applied Demography (Swanson et al, 1996). Murdock and Ellis (1991:6) set out five areas where applied and traditional or 'basic' demography diverge:

1. **Scientific goal:** *Basic demography is concerned largely with explanation; applied demography with prediction*

2. **Time referent:** *Basic demography is concerned with the past; applied demography with the present and future*

3. **Geographic focus:** *Basic demography is concerned with international or national patterns (often studied using individual data); applied demography with aggregate data for small areas*

4. **Purpose of the analysis:** *Basic demography is concerned with the advance of scientific knowledge, especially generally theoretical knowledge of causes; applied demography with the application of knowledge to discern the consequences or concomitants of demographic change*

5. **Intended use of analytic results:** *Basic demography is concerned with the advance of knowledge and the sharing of that knowledge with the scientific community and the general public; applied demography with the use of research results to inform decision making among non- demographers*

(Murdock & Ellis, 1991:6)

This project meets the criteria set out by Murdock and Ellis (1991:6) which separates applied and basic demography. The focus on the accuracy of small area population statistics which defines this research, aims to inform users of these statistics, both demographers and non-demographers, of the potential levels of error present within the population estimates and projections The final point on this list, concerned with how the analytic results are used, is also highly relevant to this project. Results of the analysis of this research may have the potential to better inform decision making and policy, through the quantitative analysis of accuracy and also by furthering the understanding how such demographic statistics are used by local planners.

4.3.2: A Mixed Methods Approach

As well as understanding where this research sits within the field of demography, it is also important to understand the rationale behind the methodological approaches taken in this thesis. While this project may contain many of the features outlined by Murdock and Ellis (1991) which would place it firmly in the field of applied demography, it also takes on some of the features of more traditional or 'basic' demography. Although this is an analytical project, focusing upon the performance of a range of estimation and projection methods, this research also aims to try and explain why there may be differences in the accuracy of population statistics between areas, as well as how inaccuracies may have real world implications for users, planners and policy makers. In order to understand how local planners engage with small area demographic statistics, and how they consider issues such as accuracy, qualitative methods were used to collect these experiences. This thesis therefore, takes a mixed method approach, using quantitative methods to empirically capture variability in error, while qualitative methods are used to capture the ways in which the demographic statistics and their error are used and understood in the planning process.

Mixed methods approaches have been growing in popularity in recent years, and have been described as 'the third methodological movement' (Cameron, 2011; Evans et al, 2011), becoming a valid methodological approach alongside quantitative and qualitative analysis. When using the term 'movement' to describe mixed methods, Creswell and Garrett (2008:322) explain that; "*The term "movement" is emphasized to suggest that mixed methods is a growing trend in research methodology".* Describing this growth in popularity further, Creswell and Garrett (2008) explain that while for many years, researchers had been combining quantitative and qualitative methods in their work, it was only in the 1980s that the concept of mixed methods emerged, defining this combination of methods as a distinct conceptual approach to research which has only been growing in popularity since.

When defining mixed method approaches, Cameron (2011) states that the definition is contested with many different descriptions of mixed methods provided, however, broadly, this approach is defined as; "*Mixed methods investigations involve integrating quantitative and qualitative data collection and analysis in a single study or a program of inquiry. This form of research is more than simply collecting both quantitative and qualitative data; it indicates that data will be integrated, related, or mixed at some stage of the research process"* (Creswell et al, 2004:7). Building on this general definition, Johnson & Onwuegbuzie (2004) put forward their own description of the role of a mixed methods approach which closely reflects the aims of this research. They explain that, *"words, pictures and narrative can be used to add meaning to numbers"* (Johnson & Onwuegbuzie, 2004:21). This definition of mixed methods as a way of using both quantitative and qualitative data to better understand a problem is particularly relevant to the analysis conducted in this research, where qualitative analysis is used to contextualise the findings from the quantitative, statistical analysis. While quantifying the error which may be present in small area population statistics provides an insight into the expected levels of accuracy for a range of methods; it fails to provide any understanding of what different levels of error mean in reality when these statistics are used to inform planning and policy making. In addition to this, a purely quantitative comparison of methods, without taking into account the skill level and resources held by local analysts on the ground, would provide limited results and recommendations, advocating particular methods without taking into account the practicality of applying these methods in reality.

Despite the mixed methods approach becoming a more notable way of conducting research, there is some criticism. One issue which was raised by Hesse-Biber (2010:10) is that, in many cases, mixed method approaches result in '*method-centric*' projects which put the '*cart before the horse'*. When expanding on this point, Hesse-Biber (2010) explains that the practice of mixed methods research results in situations where researchers choose a mixed approach then make the research questions fit with the methods, with no real rationale behind why a mixed method approach was taken. However, in the case of the research conducted in this thesis, a mixed methods approach was required in order to address the research questions set out in the previous section. While research questions one and two require a quantitative approach in order to compare the accuracy of methods and explore the impact of area characteristics; for the third research question, which seeks to explore how users engage with these statistics and the associated error, there is no quantitative approach which would be appropriate. Together, the two aspects of this research aim to provide a more holistic and comprehensive evaluation of small area population statistics in Scotland, providing an indication of the level of accuracy which may be expected from these estimates and projections, as well as generating a deeper understanding of how users consider the concept of accuracy regarding these statistics, and how this impacts upon how they are used to inform planning and policy making. More information regarding the methodology used in this thesis to address the research questions set out above, will be described in further detail in the coming sections of this chapter.

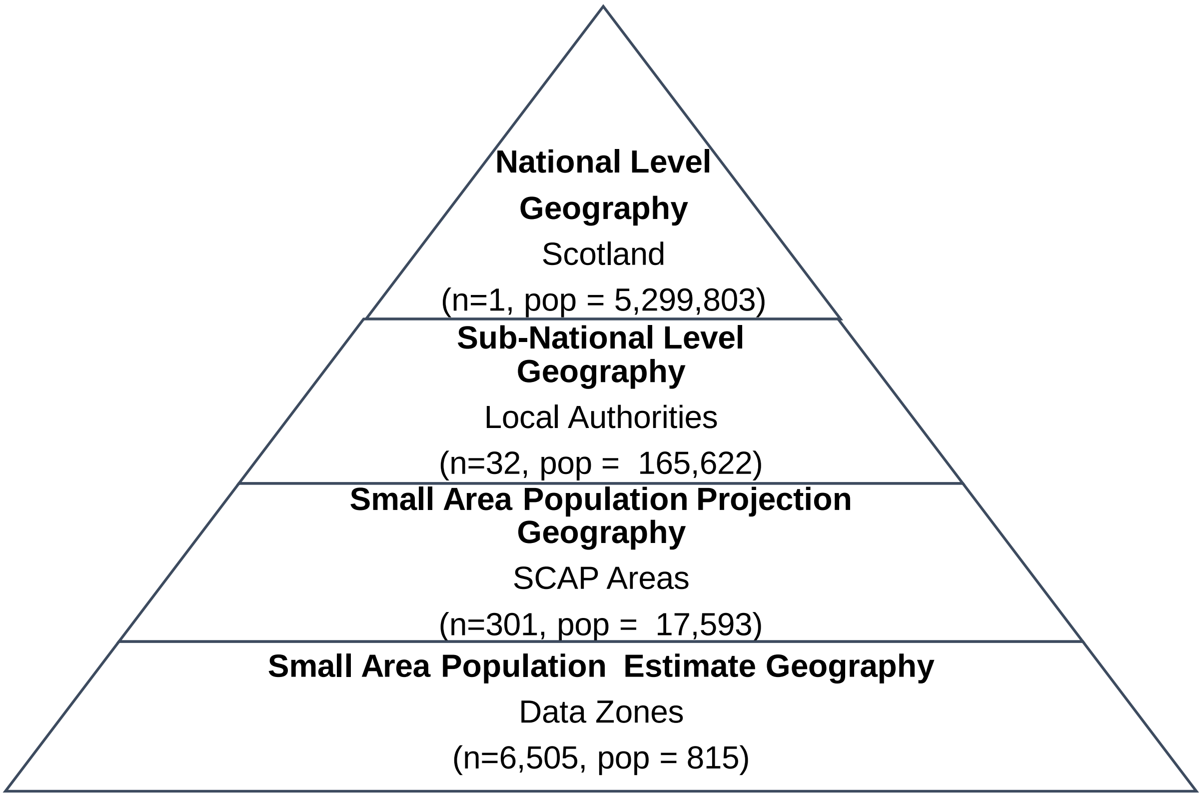
4.4: QUANTITATIVE ANALYSIS

This is a mixed methods research project, drawing on both quantitative and qualitative methods to attempt to answer the research questions outlined above. This means that a range of different data types are required to conduct the analysis. The first of the two analysis chapters are quantitative based, using statistical analysis to evaluate the accuracy of population estimates and projections while the final analysis chapter, which explores the users' relationship with these population statistics, is predominantly qualitative, using questionnaires and interviews to explore the everyday practice of using population estimate and projection accuracy in policy settings. This section will outline the data and methodology used to carry out the statistical analysis used in the quantitative chapters 5 and 6.

4.4.1: Scotland's Small Areas

While this project focuses on small area population estimates and projections, there is no standard measure of a small area, with Wilson (2015:335) stating that *"There is no universally agreed precise definition of 'small area' in demographic studies*". Even within this research, there is no consistent definition of a 'small area' with different geographies used in the analysis of population estimates and population projections, based upon the geographies used by NRS.

Figure 4.1: Geographical Structure of Scotland[1]



In Scotland, the annual mid-year small area population estimates are produced for areas of geography called data zones. These data zones are Scotland's smallest administrative area of geography, designed to consist of populations of between 500 and 1,000 people (Office of the Chief Statistician, 2004). In this study the 2001 data zone boundaries were used, based upon the 2001 census output areas. At the 2001 boundaries, there were 6,505 data zones covering the whole of Scotland, however,

[1] Number of areas within geography and average population in brackets. Average population figures from 2011 census data and author's analysis

in this research only 6,500 will be included in the analysis. Three of these data zones were not included in the census data as the population of these areas was zero (NRS, 2011), while the remaining two may not have been included because of special or protected populations. A list of data zones excluded from this study can be found in the appendices.

While data zones are used in the production of the small area population estimates, these areas are not an appropriate geography for producing small area population projections due to their small populations, below the 3,000 threshold considered to be required for a reliable projection (NRS, 2016). For this reason, geographies named Sub-Council Area Projection (SCAP) areas were used in NRS' 2012 based small area population projections (NRS, 2016), with these same areas used in this analysis. These areas were defined by NRS, in consultation with local authorities. Twenty-one of Scotland's thirty-two local authorities chose multi-member wards as their SCAP areas with the remaining eleven choosing to have custom geographies which were more meaningful and useful to them (NRS, 2016). Overall, there are 301 SCAP areas in Scotland each of which was created by aggregating data zone level data using a best-fit lookup table. A full list of the type of SCAP areas used by each local authority, as well as details of their population size can be found in Appendix B.

4.4.2: The Population 'Truth'

In order to evaluate the accuracy of both the population estimates and projections, a population "truth" must first be defined. In this project, the population truth is the population figures recorded in the 2011 census[2]. This is an approach advocated by Houqe (2008:126) who argued that *"any ongoing program of population estimation must periodically evaluate the results of past estimation against actual census counts of the population".* This is the approach taken in this study, extending it to include population projections, using historic population estimates and projections in order to compare the results to the 2011 census. While the use of a census as a measure of the true population is used in other studies of this type (Isserman, 1977: Murdock et al, 1984), it should be noted that there are some limitations of treating the census population as the "truth". Although the census attempts to capture the total population of an area, it relies on individuals completing the census accurately and submitting their responses. Both of these processes open the information recorded in the census up to potential error, as mistakes can be made in the completion of the census form or an individual's failure to complete it altogether. Martin (2010) explains that internationally, censuses generally fail to capture the total population, with evidence suggesting that there are individuals missing from official

[2] The evaluation of population estimates was also conducted using adjusted population estimates as the population 'truth' with overall findings of this research found to be the same as those produced when using the census as the 'truth'. NRS (2014) state that difference between the census and revised estimates were fewer than 50 people for two thirds of data zones.

counts. Furthermore, Martin (2010) explains that the undercount present in the census does not occur evenly, but has distinct spatial and social patterns, with individuals from certain areas or demographic groups more likely to be missed than others. This is an issue which is also highlighted by NRS themselves, who explain that, while every effort was made to ensure that everyone was included in the 2011 census, there are some individuals missing, with those from certain groups more likely to be missed than others (National Records of Scotland, 2013). In response, further work is conducted following each census to independently improve its accuracy using a Census Coverage Survey that adjusts the census population figures for non-responses. Overall, in 2011, Scotland's census is reported to have achieved a 95% response rate from the public, with the Census Coverage Survey used to account for the missing 5%. Following this adjustment, NRS state that: *"NRS is now confident that the census population estimates for all areas represent 100 per cent of people usually resident there"* (National Records of Scotland, 2012:4). This confidence in census methodology underpins its use as the truth in the previous research in this field. In this research therefore, the 2011 Scottish census has been used as the best estimate of the true population and the benchmark to which estimates and projections will be compared.

While the census will be used to evaluate the population in 2011; population estimates (adjusted following release of the 2011 census) are used to evaluate population projections in other years of the projection (2007-2010). The population estimates were corrected by National Records of Scotland following the release of the 2011 census and the full methodology and rationale behind the adjustment of these methods can be found on the NRS website[3].

4.4.3: Population Estimates

The first of the analysis chapters in this research (Chapter 5) will focus on the evaluation of small area population estimates, in particular those produced using the Cohort Component method, comparing their accuracy with estimates produced using alternative methods. In this research, the term "estimation methods" will be used as a collective term to refer to the processes or methods used to produce population estimates. This study compares six estimation methods; the Cohort Component method and five alternative estimates which were developed as part of this research. For reasons given in the previous section, all population estimates used in this study are for the year 2011 to allow for a direct comparison to the 2011 census. Much of the data required for this chapter was accessed from the National Records of Scotland website. Both the official unadjusted NRS small area population estimates developed using the Cohort Component methodology prior to the release of 2011

[3] (The full methodology of how these population estimates are revised can be found: https://www.nrscotland.gov.uk/files//statistics/small-area-population-estimates/2002-2010-revised/sape-publication-mid-2002-2010.pdf)

census, as well as much of the data required to produce the alternative population estimates were directly accessed from the “Statistics and Data” page.

The Ratio Change and the Average method required data which was not publicly available, requiring an indicator of change in population size. This type of data is usually gathered from administrative sources considered to accurately serve as a proxy for the true population size (Park, 2018). In this research, the indicator detail used to produce these population estimates was aggregated counts of the number of individuals in each data zone registered with a GP with age detail. The data used to produce estimates using this approach was informed by the methodological approach taken by ONS whereby GP register data is used as an indicator of the population.

To produce estimates using these methods as authentically as possible, the patient register data from 2001 to 2011, broken down by age was required. This data was requested from NHS National Services Scotland, part of NHS Scotland. While this request was granted, there were instances of data suppression, where data was withheld to ensure anonymity. The smallest number disclosed in this patient register dataset was three, suggesting that the population in cases where the data was suppressed is either one or two. To overcome this issue of missing data, where there was no population information in the first year, 2001, the population was set to one, while in the following years, the population was assumed to be the same as the previous year. Overall, in this dataset, 7 data zones had issues with data suppression out of the 6,500 included in this study. A full list of the data zones and age bands affected by the data suppression and an explanation of how the patient registers were constructed can be found in the appendices.

4.4.4 Population Projections

As with the analysis of the population estimates, when evaluating the performance and accuracy of population projections, a number of different methodologies were compared. There are four different projection methods which are included in this study, which broadly fall into two categories; the Cohort Component method used by NRS in their official sub-council estimates defined in this thesis as a complex method for reasons discussed in the Review of Methods in Chapter 3 and simpler mathematical methods which include the Geometric, Exponential and Arithmetic methods.

4.4.4 a): The Cohort Component Method

As with the evaluation of small area population estimates, the Cohort Component method was included in this study as it is one of the most commonly used methods for producing population projections for a variety of geographies and is employed by many national and international agencies (Rowland, 2003), including Scotland. All data required to produce population projections using this method was provided by NRS, as part of the collaborative partnership for this research, for the years 2001 to

2011. The period from 2001 to 2005 is used as a training period in which past trends in fertility, mortality and migration, and local differentials established. These past trends are then used in the production of a continuation projection, launching in 2006 and ending in 2011. There are several different pieces of data which were required to produce these projections for each of Scotland's SCAP areas. A full account of the data used and methodological approach taken by NRS and emulated in this research has been published by National Records of Scotland (2016)[4], however a brief account of the data used will be included in this section.

In Scotland, the POPGROUP software is used to produce population projections following the Cohort Component method. POPGROUP comprises an Excel-based "*suite of demographic software to generate population, household, labour force and other derived projections for specified geographical areas/population groups*" (Edge Analytics, 2019). The software is the industry-standard for *"local area demographic analysis and forecasting"* (Edge Analytics, 2019) and is widely used within the UK, including by organisations such as NRS, NISRA, the Welsh Government, ONS, local authorities and other public and private sector organisations (Edge Analytics, 2019). The POPGROUP software produces projections using the Cohort Component method, employing historical fertility, mortality and migration data, along with standard national rates, special population data and constraint data. The sources of this data input into this software will be outlined further in this section.

Broadly, Simpson & Snowling (2011) describe the data required to produce population projections using the Cohort Component method via the POPGROUP software as; *"calculated using a single-area cohort component model with single year of age and annual cycles, carried out using the POPGROUP software. The software demands entry of single-year-of-age schedules of fertility, mortality and transition migration in- and outflows with one or two external areas. Rates are expressed as events per thousand population specific to males or females with age at the start of the projection year"* (Simpson & Snowling, 2011:113).

When producing small area population projections using POPGROUP, and following the NRS methodology, there is a three stage process (Simpson, 2019). The first stage of producing the projection entails preparing a training projection which covers the population trends in each local area for past years, concerning birth, death and migration data for each year of the projection by local area. This establishes how the population has changed in the past and provides context for how it may change in the future. In the second stage of the projection, assumptions are produced, using data from the training projection to produce differentials. These differentials show the fertility, mortality and in/out migration rates for each local area. Fertility and mortality differentials are produced by comparing local birth and death data to national rates, to establish whether local fertility and mortality rates are above or below the national rate. Migration assumptions are calculated indirectly, by examining changes in the population which cannot be accounted for by the 'ageing on' of the population from one year to the next, this then calculates in and out migration by sex and single year of age. Due to this method of accounting for migration, internal migration from within the UK and overseas migration are not differentiated. The third and final stage of this

[4] https://www.nrscotland.gov.uk/files/statistics/scap/scap.pdf

projection uses these assumptions to project forward past demographic trends into the future based upon past, observed, local demographic trends, as well as future changes in fertility and mortality which are expected for Scotland as a whole (Simpson, 2019).

Following the methodology used by NRS to produce their 2012-based experimental small area population projections, as mentioned previously, the migration data input into the POPGROUP software combines both internal and international migration to give a single flow for out-migration and a single flow for in-migration. While POPGROUP does provide users with the opportunity to process domestic and overseas migration separately, as this project follows NRS methodology, it combines internal and international migration into a single data source. When describing how migration is included in their small area projections, NRS state;

"*POPGROUP calculates estimates of local migrants and age-specific migration rates using the difference between the annual small area population estimates (SAPE). In and out migrants are estimated separately but only the net impact for each age-sex group is known from the past. Therefore the in and out flows estimated by POPGROUP are indicative rather than a true estimate of in and out flows experienced over the period. Migrant age-sex groups and age-sex-specific-migration rates are calculated over a five year period 2008 to 2012. The balance of short-distance, long-distance and international migration is unknown."* – NRS (2016:62)

This description explains how, as migration is calculated indirectly using differences between annual population estimates, it is not possible to distinguish between internal and international migration. This approach is consistent with the advice given in the POPGROUP user guide, designed as a tool to guide users in the production of small area population projections. In this guide, it states that, unlike for larger areas, when producing projections for sub-council areas, only two migration flows should be used, one for all in-migration and one for all out-migration (Simpson, 2019).

This combination of internal and international migration could be seen as problematic for users, who would use these projections to understand the drivers of population change in their areas and would be interested in whether migration rates were driven by internal migration within Scotland, from elsewhere in the UK or from overseas. As Scotland has three migration streams, internally within Scotland, from the rest of the UK and from elsewhere in the world, a multi-regional approach to processing migration may be more appropriate than the approach currently used by NRS. Using a methodology developed by Andrei Rogers, Rees et al (2015) describe how by using a multi-regional approach, the separate origins and destinations of migrants can be taken into account in the projection model, treating internal and international migration separately. This is in contrast to the bi-regional approach currently used in Scotland which only processes a single flow of in-migration and out-migration. In a consultation report produced for NRS, Rees et al (2015), explicitly recommend using a multi-regional cohort component approach for producing Scottish population projections, with this approach stressing that distinct migration streams should be recognised. The migration streams identified in this report were; between council areas in Scotland, between Scottish council areas and countries within the UK, and between Scottish council areas and the rest of the world. However, it is important to consider that this report by Rees et al (2015) refers to approaches taken in the production of sub-national population projections, rather than the sub-council projections which are the focus of this research. Despite the potential methods outlined in this report, there is no reference as to whether these approaches are possible when dealing with small, sub council areas. Many issues regarding the production of high quality population statistics at a local level are concerned with data accessibility and reliability, with data produced for small areas more prone to error and some data unavailable at a local level due to issues with privacy. This may mean that while multi-regional approaches to incorporating migration into population projections may be preferable, at a local level, it is not clear that the quality of sub-council area migration data, support a the multi-regional modelling of migration.

The bi-regional approach to processing migration currently used in Scotland may be problematic to users interpreting the results of projections produced by combining different types of migration. However, as this research seeks to evaluate the projections produced using the methodology followed by NRS, it is important to recreate this methodology as closely as possible to give an indication of 'accuracy' and usefulness of these new, small area population projections, despite any limitations that may exist in this methodology.

All the input data used to produce the small area population projections following this method can be found in Table 4.1.

Table 4.1: POPGROUP Input Data

Input Data	Background	Source
Standard/National Rates	Contains data covering the National (Scottish) rates of fertility, mortality and migration	Prepared by Edge Analytics and provided with the POPGROUP software
Base Population	The starting point for producing an estimate or projection using the Cohort Component method.	2001 mid-year population estimates aggregated from data zones to SCAP areas
Births Data	Number of babies born by sex for each year over the training period (2001-2006)	Mid-year births data from NRS aggregated from data zones to SCAP areas
Death Data	Number of deaths by sex and age over the training period (2001-2006)	Mid-year death data from NRS aggregated from data zones to SCAP areas
In-Migration Data	Distribution of in-migrants (UK and overseas) by age and sex expressed as a percentage	Calculated using National Rates and Training projection
Out-Migration Data	Combined UK and overseas out migration rate per 1000 people by age and sex	Calculated using National Rates and Training projection
Special Populations	Population groups seen as separate to the general population e.g. students living in halls of residence, prisoners and the armed forces by sex and single year of age	Provided by NRS
Sub-National Population Projections (SNPP) for Council areas	Sub-national population projections by sex and single year of age used to constrain projections (optional and not used in this study)	National Records of Scotland

Table 4.1 Outlines the input data required to produce the population projections used in this research using the POPGROUP software. As can be seen from this table, all of the input data was sourced from the National Records of Scotland and was based upon the methodology used to produce the sub-council area population projections published by NRS in 2016 (Simpson, 2019).

4.4.4.b). Mathematical Methods

For each of the mathematical methods used in this study, the same data sources were used. While the Cohort Component method, required several different datasets, for these simpler methods, the only data needed was the census population of each small area by age for 2001 and the population estimate for each small area by age for 2006 to create a five-year projection ending in 2011.

4.4.5: Area Characteristics

As previously discussed in Chapter 2, there is some evidence to suggest that the demographic composition of an area may have an impact on the accuracy of population estimates and projections. In order to explore the influence of demographic factors further, a range of area characteristics were used in this research. The types of area characteristics can be split into two categories. The first of these is concerned with the demographic composition of the areas, based upon the characteristics of the individuals who live in the area. The second is concerned with characteristics of the area as a whole, such as deprivation level or rurality. The use of particular characteristics in this analysis was informed by the previous research discussed in Chapter 2, which highlighted how both certain demographic groups or types of areas may result in different patterns of population growth.

For the first of these area characteristic categories, data was used from the 2011 census[5]. This ensured both consistency in terms of the area used in this study as well as a consistency in time. Data zone level data was used, with aggregation required for the analysis of population projections which were produced for a higher level of geography. This aggregation was carried out using a lookup table produced by NRS which matches 2001 data zones using a best fit methodology, based upon the weighted centre of the data zone (NRS, 2016).

As well as examining the role of area demographics on the accuracy of population estimates and projections, the accuracy of population estimates was explored further by looking at the characteristics of the area more generally. In this part of the research, the accuracy of population estimates was compared, based upon an areas' level of deprivation and urban/rural classification. This was information which was not recorded in the census but was gathered from alternative sources.

In order to study the relationship between estimate error and area deprivation, a definition of deprivation had to be set. In Scotland, the official tool for classifying areas based upon deprivation, is the Scottish Index of Multiple Deprivation (SIMD). This tool was developed by the Scottish Government and aims to identify areas experiencing multiple deprivation using a number of indicators, covering many aspects of life. The SIMD uses 38 indicators or 'domains' covering issues such as education, health, crime, access to services and unemployment to measure the deprivation of an area. Each data zone is then ranked from 1 (the most deprived) to 6505 (the least deprived), (Scottish Government, 2016). In this study the results of

[5] https://www.scotlandscensus.gov.uk/ods-web/data-warehouse.html#bulkdatatab

the 2009 SIMD will be used as this was the version in place in 2011, before the publication of the next version in 2012. The dataset used to match each data zone with its SIMD rank was found on the Scottish Government open data website (Statistics.gov.scot). When examining the role of deprivation on the performance of population projections, an average SIMD score was calculated, using an average of the deciles from all data zones within each SCAP area.

As well as area deprivation, settlement type was also an area characteristic explored in this research. As with the SIMD, the official Scottish Government's standardised classification of settlement types was used. In this study, the Scottish Government's six-fold Urban/Rural Classification system was used. The definitions of each of these classifications are outlined in the table below:

Table 4.2: Scottish Government six-fold urban/rural classification

	Scottish Government 6 fold Urban Rural Classification
1. Large Urban Areas	Settlements of 125,000 or more people.
2. Other Urban Areas	Settlements of 10,000 to 124,999 people.
3. Accessible Small Towns	Settlements of 3,000 to 9,999 people and within 30 minutes' drive of a settlement of 10,000 or more.
4. Remote Small Towns	Settlements of 3,000 to 9,999 people and with a drive time of over 30 minutes to a settlement of 10,000 or more.
5. Accessible Rural	Areas with a population of less than 3,000 people, and within a 30 minute drive time of a settlement of 10,000 or more.
6. Remote Rural	Areas with a population of less than 3,000 people, and with a drive time of over 30 minutes to a settlement of 10,000 or more.

Source: Scottish Government (2018)

As with the SIMD data, the settlement type was matched with each data zone using a lookup table available as part of Scotland's open access official statistics (Statistics.gov.scot).

Overall, all the data described in this section was used in the analysis which aimed to answer the first two research questions explored in this study. The final question is concerned with how users of population estimates and projections engage with local demographic statistics and how they understand and think about accuracy. The qualitative methodology which was used to approach this question, along with how the data outlined in this section was used to answer the first two questions will be discussed in further detail in the subsequent sections of this chapter.

4.5: METHODS FOR PRODUCING SMALL AREA ESTIMATES/PROJECTIONS

This section will define the methods included in the analysis in this research, as well as the processes which were used to produce them.

4.5.1 Population Estimates

As discussed previously in this chapter, this project seeks to evaluate the accuracy of the small area population estimates produced by NRS and compare the accuracy of these estimates to those produced using alternative methods. In this study, six methods, including the NRS estimates were compared. While the estimates produced by the NRS could be accessed directly from their archives, the estimates produced using alternative methods were created specifically for this project. Like those produced by NRS, they were age specific estimates for data zones. The methodologies for producing all the population estimates used in this study are outlined below:

1. **Cohort Component Method:-** This is the method used to create the population estimates produced by the National Records of Scotland. The Cohort Component method uses the population equation to update the past population based upon the number of births and deaths occurring in the year, as well as accounting for net migration. A full account of the methodology used to apply this method in Scotland is provided by NRS (2018)[6].

Equation 4.1: Cohort Component Method

$$P_{i,t+k} = P_{i,t} + B_i - D_i + I_i - O_i$$

Where:

$P_{i,t}$ = Population of area i at time t (the launch date)

$P_{i,t+k}$ = Population of area i at time t +k (the target year)

B_i = Births in area i between time t and t+k

D_i = Deaths in area i between time t and t+k

I_i = In-Migrants in area i between time t and t+k

O_i = Out-Migrants in area i between time t and t+k

Source: Swanson & Tayman (2012:195)

[6] https://www.nrscotland.gov.uk/files/statistics/population-estimates/sape-17/sape-17-methodology.pdf

Equation 4.1 shows the process used to produce population estimates using the Cohort Component method. While this is the general process used to apply this method, when following the approach used in Scotland, an additional step in included. When following the approach taken by NRS, the special populations are processed separately (aged on) and then added to the estimate which is produced using the above equation.

2. **Constant Share Method:-** The Constant Share method can be considered a more simple method where the small area's share of the larger parent area will remain constant over time.

Equation 4.2: Constant Share Method

$$P_{it} = (P_{il} / P_{jl}) (P_{jt})$$

Where:

P_{it} = Child area population for target year

P_{il} = Child area population for launch year

P_{jl} = Parent area population for launch year

P_{jt} = Parent area population estimate for target year

(Source: Swanson & Tayman, 2012:127)

This method uses the data zone and local authority population figures from the 2001 census, used as the population for the launch year to calculate what share of the local authority population is present in each data zone within that local authority (Swanson & Tayman, 2012). With reference to Equation 4.2 above, the parent area refers to the local authority population while the child area denotes data zones. Should this method prove to be reasonably accurate, an advantage of adopting it for producing Scotland's small area population estimates would be, that the data required to produce it, would only have to be collected at local authority level which is considered to be more reliable in comparison to small area statistics.

3. **Shift Share Method**:- This method is somewhat similar to the Constant Share method but takes into account changes which may occur in population shares. While the Shift Share method also calculates the population of the small area based on its share of the large area, it includes a linear trend in the shares following the census (Swanson & Tayman, 2012)

Equation 4.3: Shift Share Method

$$P_{it} = (P_{jt})\ [(P_{il} / P_{jl}) + ((z/y)((P_{il} / P_{jl}) - (P_{ib}/P_{jb})))]$$

Where:

P_{it} = Child area population at target year

P_{jt} = Parent area population estimate for target year

P_{il} = Child area population at launch year

P_{jl} = Parent area population for launch year

P_{ib} = Child area population for the base year

P_{jb} = Parent area population for the base year

Z= Number of years in the post-censal period

Y = Number of years in the base period

(Source: Swanson & Tayman, 2012:128)

Equation 4.3 demonstrates the process used to produce population estimates using the Shift Share method. In the case of this research, the target year refers to 2011, the year for which the estimate was created, the base year population refers to the 1991 census and the population for the launch year refers to the 2001 census. As with the Constant Share method described above in Equation 4.2, the parent area denotes local authority areas while the child area refers to data zones.

4. **Ratio Change Method:-** This method uses indicators of the population such as GP data, child benefit figures or National Insurance numbers to measure population change. This method involved calculating a ratio change in the indicator data, assuming that the total population will change by the same amount.

Equation 4.4: Ratio Change Method

$$P_t = (I_t/I_{t-1}) + P_{t-1}$$

Where:
P_t = Population for target year
I_t = Population Indicator for target year
I_{t-1} =Population Indicator for 1 year prior to the target year
P_{t-1} = Population from 1 year prior to the target year

As previously discussed in Chapter 3, The Ratio Change method is used by the Office of National Statistics to produce the mid-year small area population estimates for England and Wales. In order to emulate this method as accurately as possible, NHS patient data acted as the indicator in this research, the same indicator cited in the methodology notes for the most recent ONS population estimates. This data was collected from the Community Health Indicator database and was organised into age-specific population counts for each data zone. As well as using the same population indicator, population estimates were produced for each year between 2002 and 2011, using the previous year's estimate as the base population for the next, in line with the ONS methodology. However, one way in which the methodology for the Ratio Change estimates produced for the purpose of this research differs from the official ONS methods, is in the inclusion of special population data. Although the ONS remove the special populations from the data before applying the Ratio Change then adding them back in, for this project the Ratio Change was applied to the total population due to problems accessing population data for special populations such as the armed forces.

5. **Average method:**- This method can be considered to be a composite method, using the estimates produced by two other methods to create a population estimate. In this analysis, an average of the Cohort Component method and the Ratio Change method will be used as this is the method employed by NISRA for the small area population estimates in Northern Ireland.

Equation 4.5: Average Method

$$\frac{[P_{i,t+k} = P_{i,t} + B_i - D_i + I_i - O_i] + [P_t = (I_t/I_{t-1}) + P_{t-1}]}{2}$$

Where:

$P_{i,t}$ = Population of area i at time t (the launch date)

$P_{i,t+k}$ = Population of area i at time t +k (the target year)

B_i = Births in area i between time t and t+k

D_i = Deaths in area i between time t and t+k

I_i = In-Migrants in area i between time t and t+k

O_i = Out-Migrants in area i between time t and t+k

P_t = Population for target year

I_t = Population Indicator for target year

I_{t-1} =Population Indicator for 1 year prior to the target year

P_{t-1} = Population from 1 year prior to the target year

6. **No Change:-** The No Change method is the simplest of all the methods included in this study and assumes that there has been no change in the population between the 2001 and 2011 census.

Equation 4.6: No Change

$$P_t = P_{t-1}$$

Where:

P_t = Target Year Population

P_{t-1} = Launch Year Population

This method was included as, should it prove reasonably accurate, it may indicate that official small area population estimates do not necessarily need to be produced annually.

All the small area population estimates used in this research have been calibrated so that population estimates sum to the unadjusted 2011 local authority population estimates produced by NRS. This replicates the approach undertaken for the NRS population estimates and in applying this approach to each method, a fair comparison is ensured. These calibrations were carried out using the Single Factor Method, as follows:

Equation 4.7: Calibration Process

Step 1: $$\mathit{Calibration\ Factor} = \frac{\mathit{NRS\ Local\ Authority\ Estimate}}{\mathit{Sum\ of\ Data\ Zone\ Population\ Estimate\ by\ Local\ Authority}}$$

Step 2: $$\mathit{Calibrated\ Estimate} = \mathit{Calibration\ Factor} * \mathit{Data\ Zone\ Estimate}$$

Where:

NRS Local Authority Estimate = Unadjusted Sub-national estimate
Aggregated Population Estimate = Sum of data zone estimates within Local Authority

This calibration process is used by NRS for their own small area population estimates (National Records of Scotland, 2012), and so was carried out for the alternative estimation methods included in this research, to maintain consistency. It is generally agreed that this calibration process occurs in order to increase accuracy (Rees et al, 2004) and to ensure that population estimates are consistent across geographical areas. Rees et al (2004) explain that, as population estimates are generally more accurate for areas where the population is larger, making the small area estimates add up to the estimate of the larger area aims to increase accuracy as well as providing consistency.

4.5.2: Population Projections

As with the population estimates, in order to evaluate the accuracy of small area population projections, several methods were compared. In this study, the term population projection refers to the future population structure that would exist if the past trends observed in an area continued consistently into the future. These projections differ from forecasts as they do not make predictions regarding how particular events or policies which may occur could impact upon population change, they are purely mathematical processes. As NRS have so far only produced one set of small area population projections, based in 2012 and ending in year 2026, there is only a limited amount of data available at this time to evaluate these projections This means that unlike the evaluation of the population estimates, the NRS produced projections cannot be used directly, but instead the methodology used by NRS will be used to derive a set of 'projections' for a historical period (2006-2011) that are evaluated and compared to alternative projection methods over the same period. The process required to produce the population projections compared in this research will be described in further detail in this section.

1. **<u>Cohort Component Method</u> –** As discussed previously, this method replicates the methodology NRS uses to produce their small area population projections.

Equation 4.8: Cohort Component Method

$$P_{i,t+k} = P_{i,t} + B_i - D_i + I_i - O_i + S_i$$

Where:

$P_{i,t}$ = Population of area i at time t (the launch date)

$P_{i,t+k}$ = Population of area i at time t +k (the target year)

B_i = Births in area i between time t and t+k

D_i = Deaths in area i between time t and t+k

I_i = In-Migrants in area i between time t and t+k

O_i = Out-Migrants in area i between time t and t+k

S_i = Special population in an area time t and t+k

Source: Swanson & Tayman (2012:195)

These projections are produced using this methodology and the POPGROUP software, details of which were discussed previously in this chapter, with further information available from Simpson (2019).

2. **<u>Arithmetic Method:</u>** The Arithmetic method is a simpler, mathematical method which assumes that the population will increase or decrease by the same amount over the projection period as the average increase or decrease in the base period (Smith & Sincich, 1992).

Equation 4.9: Arithmetic Method

$$P_t = P_o + x/y\ (P_o - P_b)$$

Where:

P_t = The small area projection for the target year

P_0 = The small area population in the launch year

P_b = The small area population in the base year

x = Number of years in the projection period

y = Number of years in the base period

(Smith & Sincich, 1992)

In this research, when applying the process described in Equation 4.9, as well as in Equations 4.10 and 4.11 to follow, the target year is 2011, the launch year is 2006 and the base year 2001. The base period refers to the years between the base and launch year (2001 – 2006), while the projection period refers to the years between the launch year and the target year (2006-2011). Census data from 2001 used for the base year and aggregated small area population estimates from 2006 for the launch year.

3. **Geometric Method:** The Geometric method is the second mathematical method used in this study. It uses the same data as used in the Arithmetic method but the process differs. While the Arithmetic method assumes that the population increases at a constant rate, the Geometric method is based on the assumption that the population compounds at constant intervals, in the same way that money in a bank account would increase with compound interest (Rowland, 2003). Applying this method requires a two-step process, first calculating the annual growth rate during the base period, then using this to project the population into the future.

Equation 4.10 a) Geometric Growth Rate

$$r = [(P_o / P_b)^{(1/y)}] - 1$$

Where:

r = Growth Rate

P_o = Population in the launch year

P_b = Population in the base year

y = Number of years in the base period

(George et al, 2004)

Equation 4.10 b): Geometric Population Projection

$$P_t = (P_o)\,[(1 + r)^z]$$

Where:

P_t = Population at target year

P_o = Population at launch year

r = Rate of Growth

z = number of years in the projection period

(George et al, 2004)

4. **<u>Exponential Method:</u>** The final method used in this study is the Exponential method. This projection method is the most similar to the Geometric method. This approach also uses the growth rate over the base period in the projection equation, however while the Geometric method works on the assumption that population compounds at constant intervals, the Exponential method operates on the assumption that the growth in the population compounds continuously. The differences in these assumptions can be seen more clearly in Figure 4.1.

Equation 4.11 a): Exponential Growth Rate

$$r = [\ln (P_o / P_b)] / (y)$$

Where:

r = rate of growth

ln = Natural logarithm

P_o = Population at the launch year

P_b= Population at the base year

y = Number of years in the base period

Equation 4.11 b): Exponential Population Projection

$$P_t = (P_o)(e^{rz})$$

Where:

P_t = Population at target year

P_o = Population at launch year

e = is the base constant (2.71828)

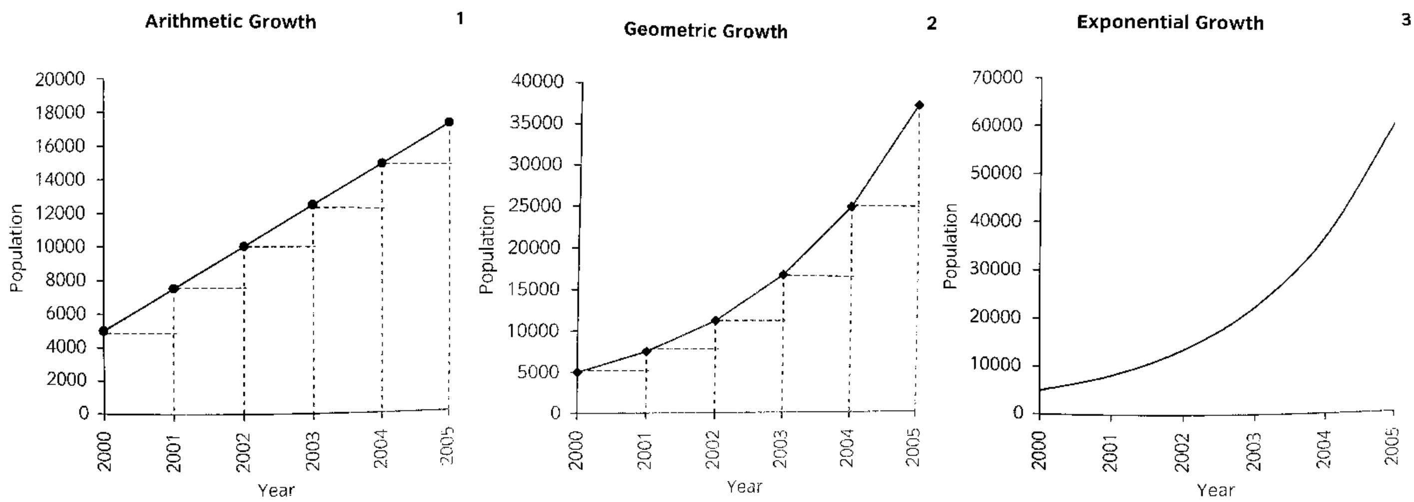
r = growth rate

z = Number of years in the projection period

(George et al, 2004)

While the three mathematical methods used in this study appear to be very similar to one another with only slight variations in how the data is used, when the methods are applied, the difference in the resulting projections can be seen more clearly.

Figure 4.2: Mathematical methods comparison



Source: Rowland (2003:47)

Figure 4.1 shows a visual example of the population projections produced using each of the mathematical methods used in this study. One of the most striking differences seen when comparing these methods is the shape of the curve produced for the projected population growth. The Arithmetic method produces a straight line, as the population consistently increases across the projection period while a curve is produced for both the Geometric and Exponential methods. This visualisation helps to explain how projections produced using each of these methods may differ from one another. The process used to compare the performance of the projections using these methods will be explained further in this section.

4.5.3: Multi-level Models to Assess Spatial Variation in Error

As the first research question in this thesis is concerned with comparing methods for producing small area population estimates and projections, it means that multiple estimates and projections were produced for the same areas. In order to fairly compare the small area population statistics used, and control for area effects, multilevel models were used to compare the accuracy of the different methods. As this analysis aims to compare the performance of a range of estimation and projection methods across the same areas, the models in this study are structured with methods nested within areas. This is in order to account for each data zone or SCAP area being included in the model multiple times. This approach is based upon previous research conducted by Lunn (1997) and Marshall et al (2017) which shared similar aims to the research in this thesis, comparing the accuracy of small area estimation methods in England and Wales. In this analysis, as in the Marshall et al (2017) paper, multilevel models were seen as appropriate based upon the assumption that estimates and projections produced by different methods for the same area will be similar, with areas which have demographics that make estimating or projecting the population difficult influencing all methods. Due to the likelihood that some areas may be more challenging to estimate than others, it is important that any area characteristics are controlled for, in order to effectively compare the performance of the estimation and projection methods examined in this study. The structure of these models and the variables included in this analysis will be described in this section.

This use of multilevel modelling will add this research to a growing body of work within the field of demography which utilises this type of analysis. Lyons-Amos (2015:i) explain that "*Multi-level models are increasingly used in social science and demography to both account for clustering within higher level aggregations and evaluate the interaction between individual and contextual information".* Multilevel analysis lends itself well to demographic analysis, with many spatial hierarchal structures nested within one another and populations stratified within geographical boundaries such as neighbourhoods. Multilevel modelling approaches allow researchers to explore how factors, in the case of this research estimate and projection accuracy, are influenced by area effects.

Explaining the growing popularity of multilevel modelling as a tool in demographic research, Matthew and Parker (2013) describe how, multilevel models are often used to provide context to studies, and explore how far certain issues can be explained by individual behaviours or by area effects. In many cases, the use of multilevel modelling in demographic research is used to study differences in fertility, mortality and migration rates between areas (Thomas et al, 2015; Roos et al, 2004; De Rose & Racioppi, 2002). In these cases, studies assume that an individual's behaviour will be, to some extent, influenced by the context in which they live over and above individual correlates of fertility. One example of this is research conducted by Forcadell-Díez et al (2020). In this study, a multilevel approach was taken to examine the relationship between social inequalities and fertility patterns for women living in Barcelona. Forcadell-Díez et al (2020) explain that a multilevel model approach was appropriate for this study as, while individual factors, such as women's age, educational attainment and country of birth were all considered important issues when considering differences in fertility patterns; contextual factors related to place were also important, with previous studies showing that abortion and adverse pregnancy outcomes are linked to areas with particular characteristics e.g. high unemployment, low income neighbourhoods. Voss (2007) describes how this use of multilevel models bridges the gap between micro and macro level demography by allowing demographers to consider both variation between individuals alongside the spatial context in which individual variation occurs. Voss (2007) describes how, while the field of demography was split between micro and macro studies over the course of 50 years, the growing popularity of multilevel analysis has helped to unite these two approaches.

In this study, multilevel modelling techniques will be used to examine the accuracy of small area population estimates and projections at a 'micro-level', exploring the effects of age, year of projection and method, and also at a 'macro-level', by including area as a level in the model. This approach will demonstrate to what extent variation in estimate or projection accuracy can be attributed to micro effects such as age or method, and to what extent variation can be explained by macro, spatial effects such as the characteristics of the area for which these statistics have been produced.

4.5.4: Defining Error

The primary focus of this research, is the examination of the accuracy of both population estimates and projections. Therefore, before accuracy can be studied, it is first necessary to define the error which will be compared across methods. In this study, the term error is used to describe the difference between the population estimate or projection and the population truth, which has previously been defined as the 2011 census, or in inter-census years the (2011) census-adjusted population estimates. This error is the dependent variable in all the regression models used in this study and is calculated as Absolute Percentage Error (APE). The APE, is a commonly used measure of accuracy in previous research of this type (Campbell, 2002) and is calculated using the formula below:

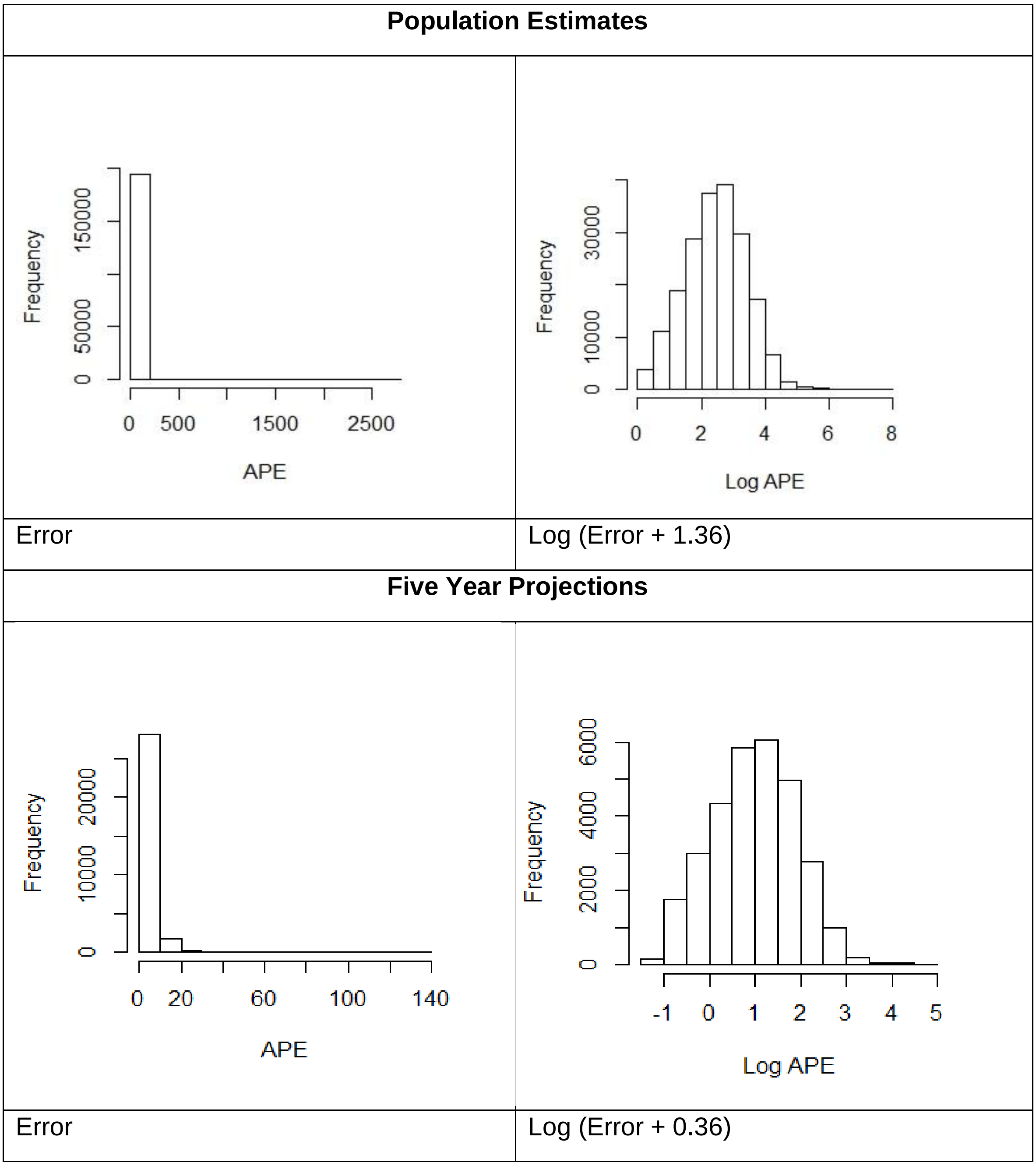
Equation 4.12: Absolute Percentage Error Formula

$$\text{Absolute Percentage error} = \left[\frac{|Population\ Estimate/Projection - Population\ Truth|}{Population\ Truth}\right] * 100$$

By expressing the error as a percentage, it allows for a better comparison between areas which is a key aspect of this research. Swanson and Tayman (2012) explain that if percentages were not used, errors in areas with large populations would skew the results of any analysis, as "*an estimate error of 1500 has a very different meaning for a place with 2500 residents than a place with 250,000 residents*" (Swanson & Tayman, 2012:268).

Once the Absolute Percentage Error had been calculated, further work was carried out to prepare the data for analysis. As the distribution of the APE variable was skewed for both the population estimates and projections it was transformed prior to regression analysis, using a logarithmic transformation. The results of this transformation for the estimates and projections used in the main analysis of this thesis can be found in Figure 4.2, while the log transformation for the eight-year projection AP"E" and Cohort Component only analysis can be found in Appendix E. It was this log APE, produced by the logarithmic transformation, which was used in the multi-level regression models as the dependent variables in the case of both the population estimates and projections.

Figure 4.3: Log Transform



Explanatory variables

In order to explore the accuracy of the population estimates and projections produced in this study fully, it is important to not only understand the scale of the error, but also the factors which may contribute to inaccuracies and the reasons why error may be higher in some areas, or for some groups, compared to others. In this research a number of explanatory variables were used which cover the areas of method, age and area characteristics (and their interaction). Details of how the data for each of these variables was prepared for the regression will be described in this section.

Model Structure

Figure 4.4: Multi-level model structure for population estimate analysis

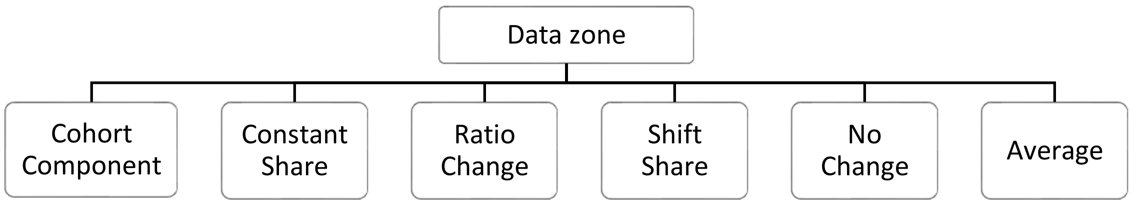
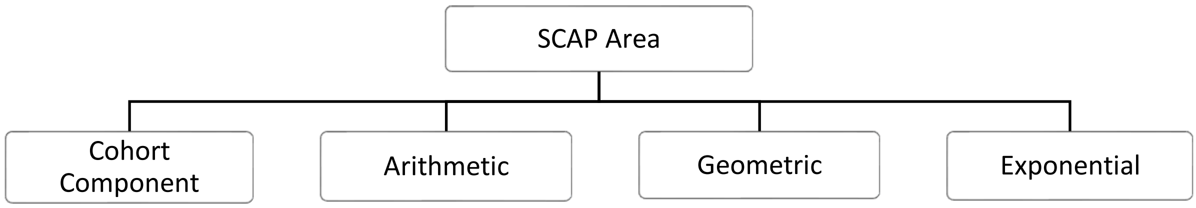


Figure 4.5: Multi-level model structure for population projection analysis



To analyse the accuracy of these methods, they were included in the model as dummy variables, with the Cohort Component method used as the reference category.

Age Groups

Age specific population estimates and projections are being used in this analysis with age was included as a variable in these models, broken down into the following age bands:

- 0-15
- 16-29
- 30-44
- 45-64
- 65+

As age data has been organised into these age bands, this variable was also included in the models as dummy variables, with the 0-15 age group used as the reference category.

While these age groups may be seen as broad, overarching groupings, they were considered to be the most effective division of age groups from a practical perspective and policy perspective as informed by interviews with local demographers. These age groupings also provide a framework through which results may be interpreted, with each of these age groups denoting particular stages of the lifecourse, for example childhood, young adults, mid-adulthood and retirement age. An example of this is that these age groups can be considered to capture trends in migration behaviour, with Tyrrell and Kraftl (2015) explaining that the 16-24 and 25-44 age groups are the most likely groups to engage in migration behaviours while the 45-64 and 65+ age groups are the least mobile. As this project seeks to explore the factors which influence error, the age groups chosen for this analysis have been chosen to tie into these lifecourse stages and to explore the influence of age in relation to this concept, as discussed in Chapter 2.

Finally, from a practical perspective, although for large national projections, it may be possible to evaluate estimates and projections by single year of age or using narrower age bands, when dealing with populations in small areas, it is more difficult to produce high quality data which is highly disaggregated. As in some areas there are very small populations of particular age groups, for example, the number of 65+ year olds in a largely student area, the estimates and projections for these age groups in these areas would have a high degree of error, should the age groups be broken down into more disaggregated groupings.

Area Characteristics

As previously discussed, this project also aims to explore how demographic factors and area characteristics can impact upon error, with all the area characteristics used in this study sourced from the 2011 census. As with the error variable, the area characteristics were also expressed as a percentage to allow a fair comparison between areas. Whereas some of the area characteristics refer to the population as a whole, others are age-specific.

Table 4.3: Population coverage of area characteristic variables

Variable	Population Coverage
Arrived within a year (International Migration) (%)	Total Population
Communal Population (%)	Total Population
Non-White (%)	Total Population
One Person Household (%)	Total Population
Overcrowding (%)	Total Population
Population Growth (%)	Age specific
Population Size	Age specific
Students (%)	Total Population
Unemployed (%)	Total Population
Unoccupied Housing (%)	Total Population

Table 4.3 outlines the area characteristic variables used in the regression models for both the population estimates and projections analysis, along with the population coverage. These variables were chosen based upon findings from previous research; both studies discussed in Chapter 2, which examined causes of spatial variation in population growth, as well as studies, such as Marshall et al (2017), which have previously examined factors which may influence the accuracy of small area population estimates and projections. As this research aims to build upon previous research, in particular the last analysis of this type to feature Scotland's small areas, conducted by Lunn et al (1998), many of the area characteristics included in the models used in this research have been specifically chosen based upon these previous studies. As findings by Lunn et al (1998) found that the characteristics of an area such as population size, population growth and percentages of Black and Asian residents, armed forces residents, institutionalised residents and unemployed residents were are all found to influence the accuracy of small area population estimates in Britain, it was important to include some of these variables in the current research. In this study population size and growth, percentage of residents who were unemployed, percentage of the population who do not identify as white and the percentage of the population living in communal establishments were all included to closely mirror the factors which were found to influence estimate accuracy in Lunn et al's (1998) research.

Area characteristics included as explanatory variables in this research have also been used in previous studies which have evaluated the accuracy of population projections. Research conducted by Chi and Wang (2018) explored how a range of issues related to area characteristics, such as socio-demographics, land use and the characteristics of neighbouring counties influence population projections. This research includes some of the characteristics included in this research by Chi and Wang (2018), including ethnicity, employment/unemployment, student population, population size and population growth.

The issues of age, socio-economic status and rurality also influenced the categories which were used for the bias analysis. As these issues were recurring themes in the previous chapter, it was important to explore not only whether these factors influenced the amount of error observed but also the direction of any error. Previous analysis conducted by NRS (2014) has pointed to some evidence of bias present in their small area population estimates, with estimates in areas with the highest levels of deprivation being revised upwards and those in the least deprived areas revised downwards (NRS, 2014). This research will examine this further, exploring how bias varies based upon area deprivation and whether this pattern of error noted by NRS (2014) exists across all methods evaluated in this research. Previous research has also indicated that population change varies between rural and urban areas, with these areas experiencing differing patterns of migration (Rees et al, 2004). This difference in migration patterns and population change between settlement types may have an impact upon direction of error observed for the population estimates produced for each area type. This is supported by a previous evaluation of population estimates produced by ONS for England and Wales, where rural areas were found to be more accurate than urban areas, with population churn deemed responsible for differences in accuracy between settlement types (Park, 2020). To explore this issue further, in this research, estimation error will be examined in relation to settlement type as defined by the Scottish Urban/Rural Classification System.

As well as factors which have been found to influence the accuracy of estimates and projections in previous research of this type, other area characteristics have also been included in this analysis. Factors such as single person households, proportion of unoccupied households and overcrowded households were also included. While there is no existing evidence from previous research that these factors will influence the accuracy of small area population statistics, these area characteristics were selected as some act as indicators of other issues, with proportions of overcrowded housing and occupied houses acting as indicators of population density. Population size is the only variable in this model which is not a percentage, and refers to the population recorded in the 2011 census (also used as the population truth) for each of the age bands. Using the population size for each of the age bands which were defined earlier in this section, provides greater context for the composition of the population of an area and offers more information about the its profile. The population change variable is also age specific and refers to the population change between 2001 and 2011, with the census for each of these years used to produce this variable. The other variables used in this study were used directly from the 2011 census and were calculated as a percentage using the total population from this census.

As the area characteristic variables were available at data zone level, they could be used directly for the population estimate analysis. However, as the population projections were produced for SCAP areas at a higher level of geography, a look-up table was used to aggregate the area characteristics data to each SCAP area before calculating each variable as a percentage, with the exception of population size. This look-up table[7] was the same tool used to produce the SCAP areas as defined by NRS, using a best fit methodology. All of the explanatory variables included in the models in this study have been mean centred to aid interpretation. This centring was carried out using the Scale() function in r.

4.5.4: Bias

As well as exploring the absolute percentage error, the issue of bias is also explored. Here, bias refers to the direction of error and whether the true population is over or

[7] https://www.nrscotland.gov.uk/files/statistics/scap/data zone2001-to-scap-lookup.xlsx

under-estimated. This analysis was conducted for the total population. In order to calculate the bias present in these population statistics, the percentage error was used rather than the absolute percentage error. The thresholds used to define these categories of bias are outlined in Table 4.4 below.

When categorising levels of error as over/under estimates or accurate estimates several thresholds of accuracy were used. As Bongaarts (2000:42) states that *"even in projections looking zero years ahead, the errors are not negligible"*, it would seem unreasonable to define only areas with 0% error as 'Accurate' in the coding process, particularly when dealing with small area estimates which are the most susceptible to error. Therefore, when coding the bias for these small area estimates, a range of definitions of 'Accurate' were included in the analysis, using a number of thresholds of accuracy.

Table 4.4: Bias Error Coding for population estimates

Scenario	**Bias**	**Percentage**
Low-Error	Over-Estimate	More than 1.2%
	Accurate	Between -1.2% and 1.2%
	Under-Estimate	Less than -1.2%
Mid-Error	Over-Estimate	More than 2.5%
	Accurate	Between -2.5% and 2.5%
	Under-Estimate	Less than -2.5%
High-Error	Over-Estimate	More than 5%
	Accurate	Between -5% and 5%
	Under-Estimate	Less than -5%

Table 4.4 shows the coding for the three error scenarios used in this analysis, which differs based upon the level of error which can be considered to be classed as 'Accurate'. In the low-error scenario, data zones with an error between -1.2% and 1.2% are considered to be accurate, with this level of error equating to around 10 individuals, based upon an average population of 814.7 across all data zones in this study. In the mid-error scenario 'Accuracy' is set at 2.5% over or under zero, equating to around 20 individuals and in the high-error scenario the range of accuracy is between -5% and 5% or 40 individuals.

When analysing bias in Chapter 5, the high error scenario will be used. This decision was taken based upon previous research by Boggarts (2000) which suggests that on average, an error of 5% can be expected for a five-year projection. While only the High Error scenario is used in the main body of this thesis, analysis conducted using the Low and Mid Error scenarios can be found in the Appendices.

4.6: QUALITATIVE ANALYSIS

In order to answer the final research question in this project, qualitative methods were used to engage with the individuals who work regularly with population statistics. In this section, the approaches used to explore the relationship between users and error will be discussed.

As the population statistics explored in this project are designed to be used for planning purposes, the way in which planners, policy makers and developers interact with, and interpret the figures evaluated in the quantitative section of this project will also be explored. The manner in which these projections and estimates are used have the potential to influence population change in itself, therefore influencing the accuracy of the figures which are the subject of this research project, as Rayer (2008:417) explains, *"Planners are in a unique position to shape the future*". The relationship between the demographers who produce population projections and the planners who use them has been referenced in previous research relating to the accuracy of these population statistics (Rayer, 2008; Keyfitz.,1972; Wilson, 2018), however, the experiences of users, and those who engage with users has often been overlooked, particularly in relation to the understanding of accuracy and error. In this section of the project, the experiences of individuals who regularly interact with the population statistics produced by NRS were explored through questionnaires, in-depth interviews and focus groups.

As the first section of this research is primarily, based on observations and statistical analysis, it could be argued that this approach is limited in its effectiveness in understanding how closely any of the estimation or projection methods meet the needs of users. While statistical analysis can measure the size of the error present in each of these population statistics, it is only by gaining a greater understanding of how small area population statistics are used and how well they inform planners and policy makers, that each of the methods studied in the quantitative chapters can be evaluated fully.

4.6.1: Questionnaires

In the first stage of this research, online questionnaires were used to reach a wide range of individuals from across Scotland, who engage with population statistics. Using the Qualtrics online survey software, a questionnaire was developed which aimed to collect data regarding the respondents' experience using population statistics as well as their attitudes towards the current population estimates and projections produced by NRS and exploring how common it was for respondents to produce their own estimates and projections.

Online questionnaires have many advantages which make them a suitable tool for gathering the views and experiences of users of population statistics. As this research aimed to reach participants from across the country, by using online survey tools, respondents could be recruited quickly and from a wide range of areas and organisations. As well as being able to reach a wider range of participants, Evans and Mathur (2006) describe how online surveys are a valuable research tool. One of the key advantages identified by Evans and Mathur (2006) is ‘question diversity’, this term refers to the different types of questions which can be asked and the control which the researcher can have over the responses. While in paper surveys, participants may select a number of responses when the question specifies ‘choose one’; when using online surveys, this issue can be controlled to ensure that responses are more reliable. The issue of question diversity and control are particularly important for this research where participants come from a wide range of organisations and departments. As this research aimed to explore both the number of individuals who produced their own estimates and projections, and the experiences of those who did produce their own statistics, ‘survey logic’ allowed different questions to be shown to participants based upon their responses to previous questions. This was a key advantage of using online survey tools which made the process more streamlined and accessible to users.

This questionnaire was developed in consultation with NRS. As a collaborating partner, the organisation offered comments and suggestions while the questions in this questionnaire were drafted in order to ensure that issues which they were interested in were also covered by this research. This questionnaire was then developed further by NRS, drawing upon questions which were established regarding the issues in this thesis before being sent to NRS service users.

In the questionnaire produced for this research, some participant information was collected, including the department in which they worked, their job title as well as how many years of experience they had in this role. These general questions about the participants’ occupation were asked to help provide context for their other responses and experiences using population statistics. While demographic data such as age and gender are commonly gathered in survey data, these factors were not considered to be relevant to the current research, with the employment profile considered to be more important in understanding their experiences using population estimates and projections. As well as gathering some personal information from participants, they were also asked about their experience using population statistics in their work and how they interpreted potential error. The aim of this section of the survey was to discover how many of the participants regularly used either population estimates, projections or both of these statistics, as well as finding out more about how population estimates and projections are used in practice. As the official population statistics are produced centrally by NRS and are widely used across Scotland, participants were asked how satisfied they were with the current output from NRS and how regularly they used these figures. In order to assess how reliant local users where on these centrally produced statistics, this questionnaire also included questions which asked participants if they had any experience of producing their own local population statistics, how they found the process and, for which geographical areas they were produced.

Participants of this questionnaire were recruited in a number of ways. Some were contacted directly, and invited to take part in the research, based upon their previous participation in a training course organised by the University of Edinburgh and funded by NRS, which aimed to teach participants how to produce their own sub-council population projections. Contacts made during this event were invited to take part in this research. Invitations to take part were also sent out to members of the Population and Migration Statistics Committee Scotland (PAMS) through NRS. Finally, the ScotStat register was also use to reach individuals who may not be engaged with NRS or may work outwith the public sector in Scotland. This register allows users of Scottish statistics to contact one another, based upon fields of interest (Scottish Government, 2020). As participants were recruited via email invitations from NRS and the ScotStat register, the sample would be largely self-selecting, however a follow up question in the survey allowed participants to give details of other individuals who may be eligible to participate or, to pass the questionnaire to a colleague, allowing for some element of snowball sampling. As a result of the anonymous ScotStat registers, the reach of NRS invitations and the potential for snowball sampling, the reach of this questionnaire is unknown. While the number of people who received information about this survey compared to the number of respondents is not known, the potential for users to pass on this survey could be seen as another advantage of using online survey tools, as it allowed participants to forward the questionnaire to relevant colleagues or provide the contact information to other potential participants instantly. Overall, 73 individuals responded to this survey which ran between March and September 2018, however, the response rate for each question varied as not all questions were relevant to all participants. As a result, some questions have a low response rate, particularly those which concerned user's experience of producing their own estimates and projections, a practice which appears to be relatively uncommon.

The responses given by participants for this questionnaire were analysed using the tools available from Qualtrics, the survey platform, using cross-tabulation and chart making features to explore the data.

4.6.2: Interviews

While questionnaires were a useful tool for collecting the general experiences and opinions of users of population statistics, in order to gain more detailed information about the experience and views of local users of population estimates and projections, in depth interviews were also conducted. This part of the research aimed to explore the responses given in the questionnaire in more detail and to gain a greater understanding of how population data is used with reference to examples from the participants' particular areas.

Table 4.5: Interview Participants

Name*	Organisation
Michael	Fife Council
Steven	Midlothian Council
David	Orkney Council
Peter	NHS Grampian
Stuart	Highlands and Islands Enterprise
Catherine	Various Experience

* All names changed for anonymity

The interviews conducted for this part of the research could be described as 'expert interviews'. While these users cannot be described as experts in the field of demography in an academic sense, each of the participants have many years' experience in using and interpreting population estimates and projections for informing policy issues, in addition to being well informed regarding the issues affecting their local communities. Bogner et al (2009:2) describe how experts can be seen as the *"crystallisation points' for practical insider knowledge and are interviewed as surrogates for a wider circle of players".* This is the case in this research, where a small sample of users, several of whom had more than 20 years' experience in their field, were interviewed to discuss their own experiences and the experiences of the teams with whom they work. As a research approach, the expert interview is a broad term, with Bongner and Menz (2009) describing three distinct approaches to this method. The first, is using expert interviews as an exploratory tool whereby the researcher develops their understanding of a problem and develops their hypothesis through interviews with experts in the field of study, who provide the researcher with 'contextual knowledge'. The second approach defined by Bonger and Menz (2009) is a 'systematizing expert interview'. In this approach, the research aims to gain exclusive knowledge held by the expert. When using this type of expert interview, *"it is not the experts themselves who are the object of the investigation; their function is rather that of informants who provide information about the real world objects being investigated"* (Bonger & Menz, 2009:47). The final interpretation of the expert interview is a 'theory generating' approach. This approach was defined by Meuser and Nagel (Bonger & Menz, 2009) and describes the way in which experts do not provide the interviewer with information or are the subject of study, but rather the interviewer uses expert knowledge to formulate a theory.

When considering the three approaches to expert interviews set out by Bonger & Menz (2009), the approach taken by this research could be seen to fall into the second approach, the systematizing expert interview. While this qualitative section of the project aims to contextualise the findings from the quantitative analysis, such as assessing how closely the participants' expectations of error match the level of error found in the quantitative analysis, the primary aim of these interviews is a way to gather the specialist knowledge the participants have gained through their work. It is this expert knowledge of population estimates and projections, as well as the specific experiences they hold in relation to their local area which can help further evaluate population statistics in terms of both their value and limitations.

In particular, the approach taken in this project would be described as a semi-structured expert interview. Described by Galleta (2013:45), *"semi-structured interviews incorporate more open ended and theoretically driven questions, eliciting data grounded in the experience of the participant, as well as guided by existing constructs in the particular discipline within which one is conducting research".* As participants in this research were considered to be 'experts', with knowledge and experience superior to that of the researcher, in terms of local demographic trends and using estimates and projections for planning purposes, this semi-structured approach allowed the key points of interest of this research to be covered, while giving participants the opportunity to provide additional information and discuss topics which they felt were relevant. This space for participants to provide additional information, unguided by the interviewer is a key advantage of semi-structured interviews, which Brinkmann (2014:286) describes as a method which makes better use of the "*knowledge producing potential of dialogues".*

In this research, general questions were developed, based upon responses to the questionnaire. These were broad, open questions which allowed participants to expand on their own experiences and provide local examples to illustrate their views, with most interviews lasting around forty-five minutes per participant.

Participants for this part of the study were recruited through the questionnaire, with an invitation at the end of the survey allowing them to leave their email addresses if they were willing to take further part in the research. When questionnaire respondents indicated they would like to participate in these follow up interviews they were then contacted with a formal invitation to take part in an interview. These invitations included a participant information sheet which outlined the aims of the interview along with any potential risks (see Appendices), in accordance to the ethical approval. Overall, four participants responded to these invitations and interviews were conducted. While only a small number of interviews were completed, they covered participants from a wide range of areas; from individuals working with small island communities, in rural health sectors and in urban centres, each of which had their own unique challenges regarding producing appropriate and useful population statistics. The interview schedule used in these interviews can be found in the appendices.

4.6.3: Focus Group

As well as using questionnaires and semi-structured expert interviews, a focus group was also held to gather the experience of users who were beginning to produce their own small area population projections. This group was chosen to complement the accounts given by expert users, by gathering the experiences of a group of users with a mixed level of knowledge and experience of using population projections. Due to the participants' mixed experiences using and producing population statistics, a focus group was chosen to allow participants to generate discussion points within the group and promote reflection based upon the issues raised by others in the group. This is a key feature and advantage of focus groups, with Finch et al (2013:212) describing how *"additional material is thus triggered in response to what they hear from others. Participants ask questions of each other, seek clarification, comment on what they have heard and prompt others to reveal more*".

The aim of using a focus group in this research was to promote discussion amongst participants in order to reveal shared experiences and ideas regarding how learning to produce their own population projections had helped them in their work, as well as the challenges they encountered. This focus group therefore highlighted common experiences and promoted debate and discussion between participants.
In this research, the group was made up of participants who had taken part in the NRS training event described earlier in this chapter. Following the training event, participants were invited back for a feedback session organised by the University of Edinburgh and funded by NRS. Here, participants gave presentations detailing how they had used the skills they had learnt in the training sessions. During this event, the focus group was also conducted, with a presentation given outlining the aims of this research to facilitate discussion. Acocella (2012) explains that, for focus groups to promote discussion and interaction between participants, a comfortable environment must be created where participants feel equal. In this research, as the participants had spent several days together during the training event and had shared experiences through the training course, participants felt comfortable engaging with discussions and comparing their experiences with one another. While there were many similarities between the participants in this research, as those taking part came from a range of organisations from all across Scotland, there were substantial differences in the local issues which impacted upon their work, creating a wide range of thoughts and opinions.

This discussion generated by the focus group, as well as the interviews and questionnaires, provided a range of information and views relating to production and analysis of locally produced, small area population projections from a range of analysts from across the country, covering areas from large urban cities to island communities. These discussions highlighted issues which were unique to the production of population statistics for local level organisations such as the shortcomings of centrally produced data and inter-organisational conflict. These views and experiences will be reflected on and discussed when trying to answer the research questions set out earlier in this chapter.

4.7: CONCLUSION

Overall, the data and methodology outlined in this section aimed to answer the research questions as fully as possible, with the mixed method approach used to explore the reliability and usefulness of population estimates and projections from a range of perspectives. While the statistical analysis described in section 4.5 of this chapter can provide knowledge regarding the accuracy of small area population estimates and projections, conducting a solely quantitative approach cannot be used to address all of the research questions. By incorporating a qualitative element into this research, it is possible to build a more comprehensive understanding of the issue of accuracy when evaluating small area population estimates and projections. This aspect of the research aims to examine the expectations of accuracy held by users of this data and to explore whether a gap exists between this observed and expected levels of accuracy for small area population estimates and projections.

Chapter 5: Evaluating Small Area Population Estimates

5.1: INTRODUCTION

This chapter will focus on a quantitative analysis of error in population estimates produced for sub-council areas of Scotland. Population estimates are a valuable tool for planners and policy makers, particularly during the intercensal period. While the census can provide the most reliable and detailed insight into the size and composition of the population, the associated time and cost means that the census is only conducted every ten years, leaving a gap in available population data. In response, Scottish population estimates are produced annually and provide a snapshot of the population size (NRS, 2018). As these estimates provide such an important insight for planners and policy makers, a range of alternative methods, including simple and complex approaches, will be evaluated to better understand the level of accuracy which can be expected for these small area population estimates and to explore which factors may influence their accuracy, or the way in which some methods may be better suited to particular area types compared to others.

This analysis will first evaluate the Cohort Component method in isolation, before comparing its performance to alternative methods. As previously discussed in Chapter 2, this method is seen as the dominant approach in the field of demography for producing population estimates and projections, and is the official method currently used in Scotland. For this reason, section 5.2 of this chapter will focus solely on the Cohort Component method in order to ensure that such a predominant method gets suitable attention. Following this evaluation, this approach will then be compared to other methods, some of which are used by statistical agencies, while others are simple methods which may be easier to apply compared to more complex methods. Some evidence from this analysis does indicate that, despite the dominance of the Cohort Component method, approaches such as the Ratio Change and Average methods outperform the Cohort Component method, while simpler methods were found to be less effective compared to the other approaches included in this research. This section (5.3) will also explore the impact of demographic factors such as age and area characteristics, as well as the interaction between these factors and methods. This is in order to explore whether some approaches produce more accurate estimates for some particular areas compared to others, with model error used to compare the accuracy of methods in contrasting areas. The final section of this chapter (5.4) will focus on the bias present in population estimates produced by different methods. As previously explained in the Methodology Chapter, this bias refers to whether the estimates over or under estimate the true population. In this section, the analysis will examine how bias varies based upon area type or demographic groups such as age, settlement type and area deprivation. When examining the link between deprivation and bias, some striking results were found, which suggest a routine under-estimation of the most deprived areas while the most affluent areas were likely to be over-estimated. All the results of this analysis will be explored in further detail throughout this chapter.

5.2: THE COHORT COMPONENT METHOD

The first of the methods examined in this research is the Cohort Component method. This method was chosen to be evaluated in isolation, as it is the most commonly used method for producing both population estimates and projections. Burch (2017) describes how this method has been 'canonised' by governments and statistical organisations to the extent that it is seen as the standard method for producing estimates and projections, including by international organisations such as the United Nations and the World Bank (Burch, 2017, 68; UN, 2017). As well as being used by these international organisations, the Cohort Component method is also the approach taken by the National Records of Scotland to produce their annual population estimates for sub-council areas (NRS, 2018). As this project focuses on the population estimates produced in Scotland, the use of the Cohort Component method by NRS, along with this method's international reputation, means this method should be given particular attention, before going on to compare the standard of these estimates, to those produced using alternative methods.

5.2.1: Range of Error

Table 5.1: Distribution of APE by Age

	Max.	Min.	Mean	Standard Deviation
0-15	217.86	0.00	11.03	14.33
16-29	541.67	0.00	15.04	19.92
30-44	500.00	0.00	12.96	15.80
45-64	925.00	0.00	7.99	15.27
65+	1220.00	0.00	11.08	24.90
Total Population	**243.53**	**0.00**	**6.64**	**9.29**

Table 5.1 shows the descriptive statistics for the error observed in the NRS' 2011 population estimates produced using the Cohort Component method (NRS, 2018). These figures show the error present in the estimates between age groups, as well as how the error varies for each of these age groups across areas.

Figures from Table 5.1 show that the Cohort Component method does not perform evenly for all age groups, with the average error highest for the 16-29 age group and lowest for the 45-64 age group. This suggests that some age groups are more difficult to estimate than others. From this table it can also be seen that the estimates do not perform evenly across areas, with large disparities between the minimum and maximum error for each age group. The most extreme example of this would be for the 65+ age group, where there were some areas with no error and one area where the population estimate was over 12 times higher than the true population. When looking at the standard deviations for each age group, it can be concluded that the largest variation in error occurred for the 65+ age group which had the highest standard deviation in this study. This may suggest that population estimates for this age group may have a wider range of error compared to other age groups.

5.2.2: Impact of Demographic Factors

In order to explore the impact of age and area characteristics on estimate accuracy, as suggested by these descriptive statistics, a multiple linear regression analysis was used. This section will seek to try to explain the cause of this difference in error between data zones in Scotland, focusing on particular area characteristics.

The area characteristics which have been selected for this model, were chosen based upon findings in existing literature as having the potential to influence the accuracy of population estimates, such as research carried out by Marshall et al (2017). While some of the variables included in the model are used as an indicator of the demographic groups discussed in Chapter 2; such as the percentage of the non-white population as an indicator of ethnicity, and age bands included as dummy variables. Other area characteristics were included as they are related to changes in demographic trends which are expected in the future. One example of this would be the predicted increase in one person households which is projected to be the fastest growing household type in Scotland (NRS, 2018). By including variables such as this in the model, it can also provide an insight into how the accuracy of population estimates may change in the future.

Table 5.2: Linear Regression Model

	Coefficient	Std. Error	Sig.
Intercept	2.097	0.010	<0.01
Arrived within a year (International Migration) (%)	0.018	0.004	<0.01
Communal Population (%)	0.000	0.000	<0.01
Non-White (%)	0.014	0.001	<0.01
One Person Household (%)	0.014	0.001	<0.01
Overcrowding (%)	-0.001	0.002	0.56
Population Growth (%)	0.002	0.000	<0.01
Population Size	-0.002	0.000	<0.01
Students (%)	0.011	0.001	<0.01
Unemployed (%)	0.008	0.002	<0.01
Unoccupied Housing (%)	0.014	0.001	<0.01
Age (Reference 0-15)			
16-29	0.297	0.015	<0.01
30-44	0.195	0.015	<0.01
45-64	-0.106	0.015	<0.01
65+	-0.053	0.015	<0.01

A multiple linear regression analysis was conducted to assess the way in which demographic factors and area characteristics impact upon the error associated with small area population estimates produced using the Cohort Component method, where a log transform of the absolute percentage error is used as the dependent variable. This model also uses the age specific population estimates produced by NRS to examine how different age bands, included as dummy variables, influence error. The regression model gave a statistically significant improvement on a null model ($F(14, 32485) = 286.1$, $p<0.00$) with an r^2 value of 0.110.

While area characteristic variables were found to help account for the variation in error present in population estimates, results from the model presented in Table 5.2 suggest that age is also an important factor. It was found that the 16-29 age group had the greatest impact upon error; with higher levels of error predicted for this age group when compared to the 0-15 age group. The 30-44 age group also had a positive relationship to error, with higher levels of error for this age group when compared to the 0-15 age group. When reversing the logarithmic transform of the absolute percentage error, it revealed that the 16-29 age group increased error by 0.33% compared to the 0-15 age group, while the error for the 30-44 age group was 0.21% higher. However, for the two oldest age groups, a negative effect on error was found when compared to the 0-15 age group although the effect was weaker for the 65+ age group compared to 45-64 year olds. This difference equated to an error 0.10% and 0.05% lower than the 0-15 age group, for the 45-64 and 65+ age groups respectively. These results correspond with the descriptive statistics presented in Table 5.1 which found that the highest average error was found for the 16-29 age group and lowest for the 45-64 age group.

When examining the factors which influence error, this model would suggest that area characteristics do have some impact upon the accuracy of population estimates produced using the Cohort Component method. With the exception of the proportion of overcrowded housing, all of the area characteristic variables included in this model were found to have a statistically significant impact upon error. Population size was the only variable included in this model which had a negative influence on error, meaning that the accuracy of population estimates increased with the population size. This result would be expected as for both population estimates and projections, it is widely understood that errors tend to be smaller in areas with larger populations (ESRI, 2007). Overall, when looking at the results from the model in Table 5.2, the percentage of the population which had arrived within a year (used as an immigration indicator) appears to have the greatest influence of all the variables included in this model, suggesting that the Cohort Component method may be less reliable in areas with high rates of immigration. This association between area characteristics and error can be seen more clearly when illustrated using a model error, as presented in Figures 5.1 and 5.2.

While the results of this analysis suggest that there is a relationship between both area characteristics and age, and estimate accuracy, this model only explained 11% of variability in error across data zones. This suggests that while age and the area characteristics help to explain some of the differences in error between areas, other factors also influence error.

Based upon the results of this model, it may be possible to measure how changes in particular area characteristics over time, may affect the accuracy of population estimates between years. One example of this is the aforementioned growing trend of one-person households in Scotland. Figures from NRS (2017) found that in 2015, one-person households were the most common household type in Scotland with around 900,000 living alone, an increase from 747,000 in 2001. This increase in single occupant households is attributed to a range of changing trends in behaviour and social norms. Dixon and Margo (2006) explain that changes in rates of divorce and delayed marriages may be responsible for some of the increase in the rise of solo living. In addition to this, NRS (2017) point to an ageing population as one of the main drivers in single occupant households. As older people are more likely to live alone, it is seen as the most likely cause of the recent changes in household composition. With projections indicating that the number of people of pensionable age is set to increase in the future (NRS, 2017); there is potential for the trend towards one-person households to continue. Using analysis from this research to model estimate error, it is possible to predict how the accuracy of population estimates may change over time based upon this projected increase of one person-households. This is only assuming that the association between error and this variable remains the same as in 2011, and the proportions of all other variables remain stable.

Figure 5.1: Model error for increase in one person households

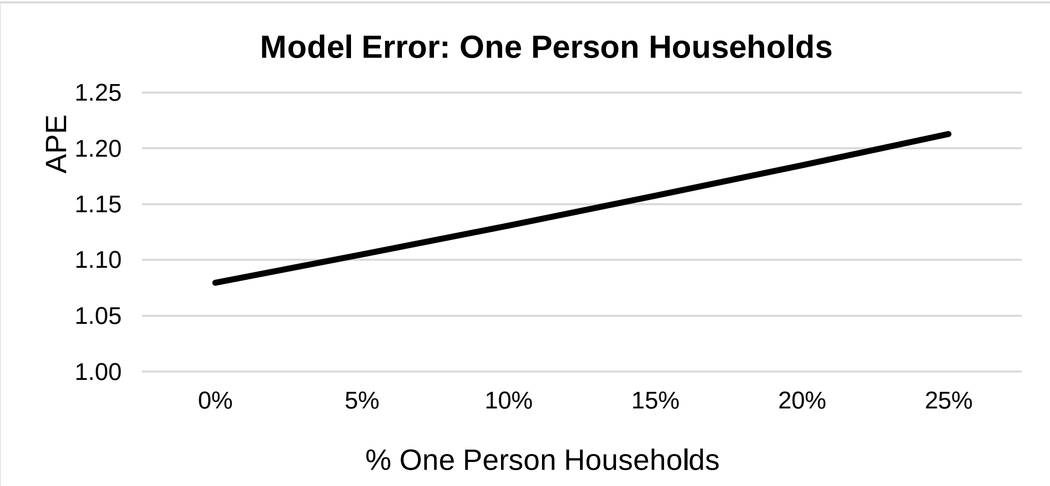


Figure 5.1 illustrates how an increase in the proportion of one-person households may affect the level of error that may be expected for an average area for 30-44 year olds. The chart shows how the error increases as the proportion of single occupant houses also increases from 0% to 25%. While there is an increase in error, it is modest with only a 0.13% error between an area with no one person households and an area where 25% of the houses have a single occupant.

In fact, when all of the variables which measure proportional changes in area characteristics are modelled, there appears to be very little variation in the level of error.

Figure 5.2: Model error for percentage variables[8]

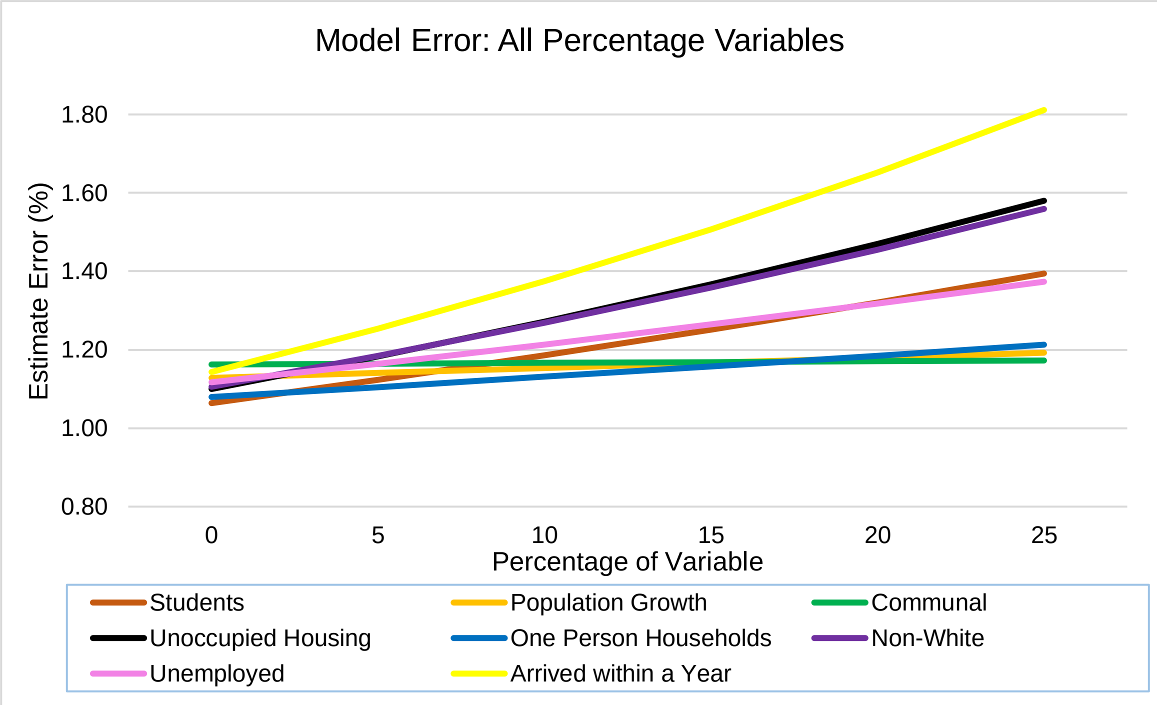


Figure 5.2 shows how the error in an average area changes, as each of the variables included as percentages of the total population increase. It can be seen that some variables had a greater impact upon error compared to others, with increases in the proportion of the population who had arrived within a year, the proportion of unoccupied housing and the size of the ethnic minority population all causing error to rise more rapidly compared to the other variables. Some of the area characteristics had very little impact on error, with variables such as the proportion of the population living in communal housing, the proportion of one person households and population growth, all having only a modest increase in error. While this modelling of the error demonstrates that not all area characteristics influence estimate error to the same extent, it can also be seen by Figure 5.2 that for all the variables in this model, there are only slight increases in error as the proportion of each characteristic increases, with the largest increase observed for the migration variable where the error increased by 0.67% as the proportion of the population who had arrived within a year increased from 0 to 25%.

[8] Range of Variables in Dataset

- % Communal Population = 0 – 93.85% (mean : 1.68%)
- % Students = 0 – 95.65% (mean : 8.24%)
- % Unoccupied Housing = 0- 61.25% (mean : 3.85%)
- % Unemployed = 0 – 21.1% (mean : 4.88%)
- % Population Growth = 0 – 1300% (mean : 13.75%)
- % One Person Households = 0 – 63.98% (mean : 16.01%)
- % Non-White Population = 0 – 84.12% (mean : 3.69%)
- % Arrived within a Year = 0 – 36.46% (mean : 0.93)
- Age band = 30-44
- Average Population Size = 815

One reason why area characteristics appear to have only a small impact upon the accuracy of small area population estimates produced using the Cohort Component method may be due to the data that is used to produce them, with this method using the birth, death and migration data to update the previous population figures (Swanson & Tayman, 2012). As births and deaths must be registered by law in Scotland within a certain period, this data can be considered reliable, with the largest potential for error coming from the delay in the event and registration overlapping with the period when the estimates are produced. While the data for births and deaths can be considered robust in its accuracy, there is a greater potential for error in the migration records. NRS (2018) describe how three sources of data are used to try and fully capture different types of migration both into and within Scotland. NHS data from the Community Health Index and the National Health Central Register are used to record internal migration within Scotland, as well as migration from elsewhere in the UK, while the International Passenger Survey is used for international migration. As these data sources are relying more on the voluntary actions of individuals (e.g. re-registering with a GP or being truthful in the International Passenger Survey), there is greater potential for error and may explain why the migration indicator in this model was found to have the greatest influence on estimate accuracy.

In order to provide more context to these findings and to evaluate the performance of the Cohort Component method more fully, population estimates produced using alternative methods will also be explored.

5.3: EVALUATING ALTERNATIVE METHODS

As well as examining how the population estimates produced using the Cohort Component method perform in their own right, it is also important to assess how this method performs in comparison to other available methods. While it was found that there was a relatively low level of inaccuracy found in the population estimates produced by the Cohort Component method, by evaluating this method’s accuracy alongside other alternative approaches, it provides more information to better judge the performance of this method, as well as answering the question of whether the Cohort Component method is the most appropriate for producing small area population estimates in Scotland.

This section aims to compare the Cohort Component method to alternative approaches. These methods include the complex methods; the Ratio Change and Average methods which are used by other statistical agencies including the ONS and NISRA, as well as the simple approaches, the Constant Share and Shift Share methods. As results from the qualitative aspect of this research, which will be presented in Chapter 7, suggested that there was a desire from local users to produce their own statistics but faced many barriers in terms of time and resources, simpler methods were included in order to explore if such methods could be utilized by these local analysts. The details of how estimates were produced using these methods are outlined in the Methodology and Data chapter. As well as including alternative methods in this analysis, a No Change method was also included to provide a benchmark of accuracy, acting as an indicator of the population data available if no estimates were produced. In cases where the population estimates outperform the No Change method, it could be seen as justifying the value of population estimates as a planning tool. However, should this No Change method prove reasonably accurate, it may indicate that official population estimates do not necessarily need to be produced annually.

5.3.1: Descriptive Statistics

Table 5.3: Range of Error – All Methods

		Min.	Max.	Mean	Standard Deviation
Cohort Component	**0-15**	0.00	217.86	11.03	14.33
	16-29	0.00	541.67	15.04	19.92
	30-44	0.00	500.00	12.96	15.80
	45-64	0.00	925.00	7.99	15.27
	65+	0.00	1220.00	11.08	24.90
	Total	**0.00**	**243.53**	**6.64**	**9.29**
Ratio Change	**0-15**	0.00	398.84	10.34	12.77
	16-29	0.00	785.98	13.15	19.80
	30-44	0.00	423.64	9.83	12.13
	45-64	0.00	2372.88	7.54	42.93
	65+	0.00	544.30	8.56	14.88
	Total	**0.00**	**105.68**	**5.50**	**6.55**
Average	**0-15**	0.00	414.47	10.21	17.50
	16-29	0.00	476.64	12.97	21.82
	30-44	0.00	477.00	10.56	17.53
	45-64	0.00	1249.15	7.41	27.43
	65+	0.00	648.00	9.29	21.69
	Total	**0.00**	**109.89**	**5.69**	**6.73**
Constant Share	**0-15**	0.01	2722.52	24.48	44.79
	16-29	0.01	2667.83	35.29	52.29
	30-44	0.00	1191.61	22.84	27.56
	45-64	0.00	1226.63	16.73	23.64
	65+	0.00	1116.59	22.87	26.27
	Total	**0.00**	**761.18**	**14.87**	**18.77**
Shift Share	**0-15**	0.00	2742.53	24.46	44.97
	16-29	0.00	1449.36	22.69	34.74
	30-44	0.00	1198.37	22.66	27.36
	45-64	0.00	1230.11	16.73	23.54
	65+	0.00	1122.69	22.84	26.22
	Total	**0.00**	**780.00**	**13.03**	**18.63**
No Change	**0-15**	0.00	2725.00	24.48	44.81
	16-29	0.00	1458.33	22.82	35.08
	30-44	0.00	1192.31	22.83	27.57
	45-64	0.00	1225.00	16.74	23.62
	65+	0.00	1120.00	22.89	26.30
	Total	**0.00**	**777.65**	**13.08**	**18.87**

Table 5.3 shows the distribution of the error by age, for each of the methods included in this analysis. These descriptive statistics suggest that the Ratio Change method and the Average method perform the best, with lower levels of error on average compared to the other methods for all age groups. Comparing these two best performing methods, it cannot be clearly concluded that one approach outperforms the other. While the estimates produced by each of these methods appear to perform similarly with one another, when looking at average error, there are some age groups which are more accurately estimated using the Average method, while other age groups were more accurately estimated using the Ratio Change method. When examining the performance of the simpler methods, it can be seen from Table 5.3 that both the Constant Share and Shift Share methods perform most similarly to the No Change method, with little difference in the average error between these three approaches. When comparing the maximum error for each method, it can also be seen that this figure was substantially higher for each of the simpler methods compared to the complex methods, with the exception of the estimates produced for the 45-65 age group where the complex methods also had substantially high levels of error.

These findings from Table 5.3 suggest that the complex methods outperform the simpler methods, with the latter performing no better than assuming no change during the intercensal period. It may also be concluded from these descriptive statistics, that the complex methods produce fewer extreme errors compared to the simpler methods. In order to evaluate each of the methods effectively and compare them to the Cohort Component method, a multilevel regression analysis was used to control for area effects. As each of the methods was used to produce population estimates for the same set of data zones, it is important to take into account that each of the data zones is included in the model multiple times, and control for this using a multilevel model structured with methods nested within areas.

5.3.2: Multilevel Analysis

In this section of the analysis, multilevel modelling techniques will be used both to compare estimation methods, as well as further exploring the effects of area characteristics and age factors on estimate error. Before examining the differences in error between methods, a variance component model was used to explore to what extent area characteristics are responsible for variations in error level. This model does not include any explanatory variables.

Table 5.4: Null Model Random Effects

	Variance	Standard Deviation
Datazones (Intercept)	0.1112	0.3334
Residual	0.7884	0.8885

Table 5.4 shows the random effects produced by the null model which aimed to examine how much of the variance in error could be explained by differences between data zones. However, as the models in this analysis use the log transform of the APE for each data zone, as explained in Section 4.5.3 of Chapter 4, to truly understand how much of the variance can be explained by data zone effects, a reverse logarithmic transformation was conducted for the variance values presented in Table 5.4. Following this process, it was found that around a third (34%) of the variance in the log of APE could be attributed to data zones and 66% of the variation due to other influences. These other influences could be variables such as age or method type. To explore the influence of these factors in more detail, they will gradually be added to the model.

Table 5.5: Method Model

	Coefficient	**Standard Error**	**P Value**
Intercept	**2.19**	0.006	<0.01
Reference (Cohort Component)			
Ratio Change Method	-0.137	0.006	<0.01
Average Method	-0.147	0.006	<0.01
Constant Share Method	0.635	0.006	<0.01
Shift Share Method	0.560	0.006	<0.01
No Change Method	0.560	0.006	<0.01
Random Effects	**Variance**	**Standard Deviation**	
Data zones (Intercept)	0.115	0.339	
Residual	0.667	0.817	

Table 5.5 shows the results of this multilevel regression model which explores the influence that each of the methods has on error when controlling for area effects. When these variables were added, the variance explained by this model increased to 37%, with 63% of the variance still unexplained by this analysis. Results of this analysis suggests that method does have an impact on the accuracy of population estimates, with each method in this model found to perform differently from the Cohort Component method which was used as a reference. The most significant finding from this model is that both the Ratio Change and Average methods have negative coefficients, suggesting that both of these alternative, complex methods produce more accurate estimates compared to the Cohort Component method. When examining the performance of the simpler methods, as with the descriptive statistics presented in Table 5.3, it can be seen that these methods performed no better than the No Change approach, with the Shift Share method performing on par

with this approach while estimates produced by the Constant Share method were less accurate than assuming No Change.

To explore the factors which influence error further, age was added to the model.

Table 5.6: Multilevel Model – Method and Age

	Coefficient	Standard Error	P Value
Intercept	**2.24**	0.01	<0.01
Reference (Cohort Component)			
Ratio Change Method	-0.137	0.006	<0.01
Average Method	-0.147	0.006	<0.01
Constant Share Method	0.635	0.006	<0.01
Shift Share Method	0.559	0.006	<0.01
No Change Method	0.560	0.006	<0.01
Reference (0-15)			
16-29	0.139	0.006	<0.01
30-44	0.008	0.006	0.14
45-64	-0.295	0.006	<0.01
65+	-0.070	0.006	<0.01
Random Effects	**Variance**	**Standard Deviation**	
Data zones (Intercept)	0.116	0.341	
Residual	0.646	0.804	

When age is added to the model, it can be seen that, as in the analysis which focused solely on the Cohort Component method (Table 5.2), the accuracy of population estimates differs between age groups. Table 5.6 shows that again, population estimates were, on average, more accurate for the older age groups, with the most accurate estimates produced for the 45-65 age group and the least accurate for the 16-29 age group. There was no significant impact on error found for the 30-44 age group, suggesting that the estimates produced for this age group were of similar accuracy to those for the reference 0-15 age group. When including age in this model, alongside the existing variables, it was found that the variance explained remained at 37%.

While these findings go some way to explaining the difference in the accuracy of population estimates between areas, to explore these differences further, area characteristics were added to the final model.

Table 5.7: Multilevel Model – Full Model

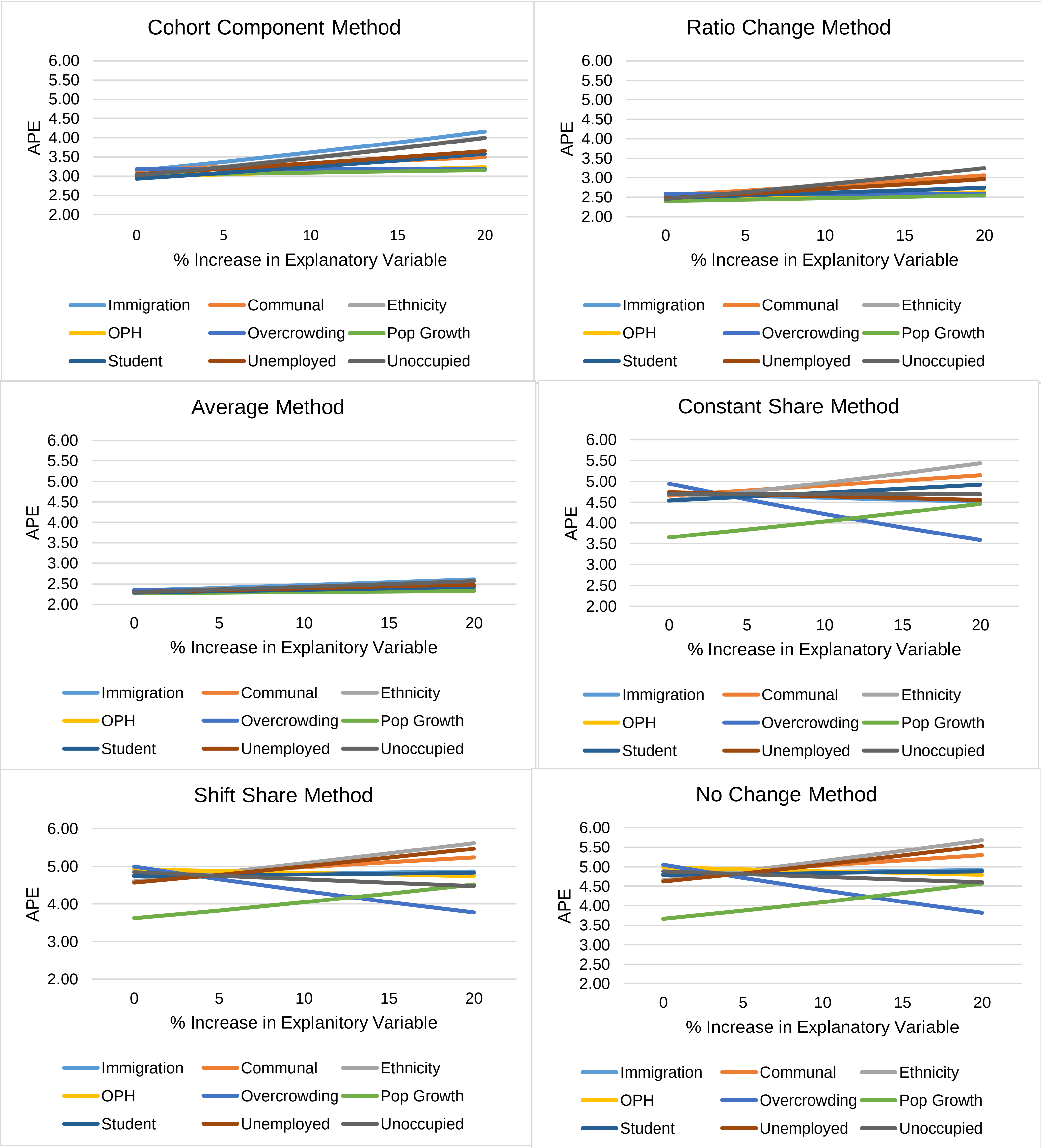
	Coefficient	Standard Error	P Value
Intercept	2.22	0.01	<0.01
Reference (Cohort Component)			
Ratio Change Method	-0.137	0.006	<0.01
Average Method	-0.147	0.006	<0.01
Constant Share Method	0.635	0.006	<0.01
Shift Share Method	0.559	0.006	<0.01
No Change Method	0.560	0.006	<0.01
Reference (0-15)			
16-29	0.152	0.006	<0.01
30-44	0.039	0.006	<0.01
45-64	-0.181	0.006	<0.01
65+	-0.125	0.006	<0.01
Arrived within a year (International Migration) (%)	0.002	0.003	0.472
Communal Population (%)	0.005	0.001	<0.01
Non-White (%)	0.012	0.001	<0.01
One Person Household (%)	0.001	0.001	0.046
Overcrowding (%)	-0.010	0.002	<0.01
Population Growth (%)	0.006	0.000	<0.01
Population Size	-0.001	0.000	<0.01
Students (%)	0.005	0.001	<0.01
Unemployed (%)	0.008	0.002	<0.01
Unoccupied Housing (%)	0.006	0.001	<0.01
Random Effects	**Variation**	**Standard Deviation**	
Data Zones (Intercept)	0.073	0.270	
Residual	0.617	0.786	

Table 5.7 shows the effects of area characteristics on error when also controlling for method and age effects. In this final model, it was again found that 37% of the variance in error between data zones was explained by this model, while 63% of the variance cannot be attributed to the demographic factors explored in this analysis.

Overall, this analysis shows that ethnicity has the largest co-efficient of all area characteristics in this model, with error increasing as the ethnic minority population increased. As with the previous analysis, population size was found to have a negative influence on error, with estimates more accurate in more populated areas.

Results from this model also show that the proportion of overcrowded houses in an area also had a negative impact upon error. This may suggest that population estimates are more accurate in densely populated areas compared to more sparsely populated areas. Interestingly, in contrast to the Cohort Component only model, when studying area characteristics for all estimation methods, it appears that recent immigration, indicated by the 'Arrived within a year' variable, has no effect on error, with no significant result found. This may suggest that the approach for calculating migration taken by the Cohort Component method, as discussed previously, may mean that the performance of the Cohort Component method is more strongly affected by the levels of migration in an area compared, to the alternative methods. In order to further explore if the influence of these area characteristics impacts upon each method differently, an interaction model was used. To compare the impact that each of the area characteristics has on each method, a model error was used to illustrate any differences. The full results of the interaction model can be found in the appendices.

Figure 5.3: Interaction Model Error[9]



[9] See previous footnote for explanatory variable figures.

Figure 5.3 shows the interaction model error produced for each of the methods examined in this research which demonstrates how the error present in each method is influenced by the area characteristics included in this model. From these modelled errors, it can be seen that the change in error as each of the explanatory variables increases differs across methods. In particular, it can be seen that the simple methods (Constant Share, Shift Share and No Change) methods behave similarly to one another as the proportions of each area characteristic change. While in some cases the estimate error decreased as the percentage of certain variables increased, in particular the percentage of over-crowded households, these model errors presented in Figure 5.3 show that for all the simpler methods, the error increased most significantly as population growth increased, with the error increasing by almost 1% for these simpler methods as population change increased from 0% to 20%. This is compared to an increase in error of 0.12% for the Cohort Component method, 0.15% for the Ratio Change method and 0.06% for the Average method. This suggests that in areas which experience dramatic fluctuations in their population size, these simpler methods may be less reliable compared to the complex methods which are more commonly favoured by statistical agencies. When examining these more complex methods, it can be seen that the Average method appears to produce the estimates which remain the most constant as the proportion of each of the area characteristics increase. While error does increase slightly, it was found that the variables which had the greatest impact upon error (% Arrived within a year, % Unoccupied Housing and % Non-White Population) only increased the APE by 0.28%, as the percentage of each of these area characteristics increased by 20%.

As previously discussed, results from the analysis in Table 5.7 suggest that the accuracy of the alternative methods included in this study may be influenced less by immigration compared to the Cohort Component method. Results from the interaction model presented in Figure 5.3 demonstrated, that the % of the population who had arrived within a year had a greater impact upon error for the Cohort Component method compared to any other method. This variable also impacted upon the accuracy of estimates produced using the Cohort Component method more greatly than any other area characteristic. It could be argued that migration appearing to have less of an impact on the accuracy of the Ratio Change method than the Cohort Component method is a surprising result, as the same data sources, which are used to measure migration for the Cohort Component method, are used as the indicator data used to produce the Ratio Change method estimates in their entirety. As the Cohort Component method uses health data such as the Community Health Index as an indicator of migration, this same data was used as an indicator of population change in the production of the Ratio Change method estimates. As discussed previously in this chapter, the use of indicator data, and in particular health register data, could be seen as unreliable. However, the key difference may be that while the Cohort Component method uses the patient registration data, as figures to include in the estimate equation, the Ratio Change method uses the data as an indicator of change. Although the figures in the patient register may not be reliable as a true reflection of the population, the changes in the number of patients registered year to year may act as a reliable indication of fluctuations in the area. It is perhaps this different approach, understanding demographic data as a reflection of change rather than a record of the population size and composition, which is responsible for the differences in the accuracy between the methods.

Figure: 5.4: Model Error for Age Band by Method

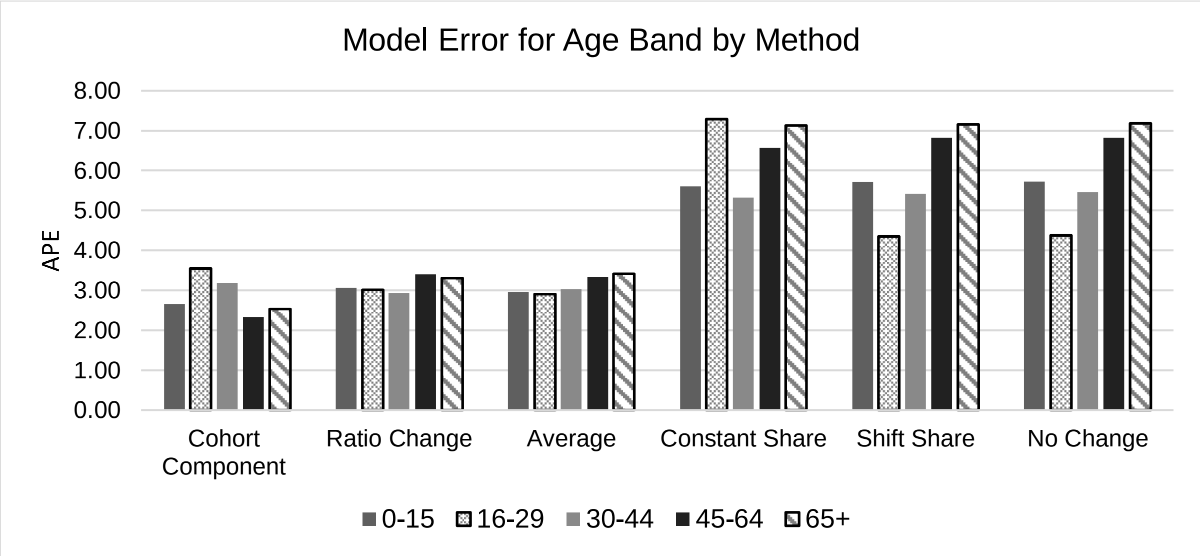


Figure 5.4 shows the model error for an average area for each age group. From this, it can be seen how the error varies between age groups for each method. Results from this analysis suggest that age had less of an effect on error for the Ratio Change and Average methods, with little variation in error between age groups compared to other methods. For these methods, there was only a difference of 0.46% and 0.52% difference between the age groups with the highest and lowest errors for the Ratio Change and Average methods respectively. While having more variation in error between age groups than the Ratio Change and Average methods, age appears to have less of an impact on the performance of the Cohort Component method compared to the simpler methods, with the Shift Share and No Change methods having the largest difference between the age group with the highest level of error and that with the lowest. Figure 5.4 also suggests that there is no one age group for which population estimates are more accurate. Although for the estimates produced using the Cohort Component and Constant Share methods, the 16-29 age groups experienced the highest level of error; for estimates produced using the Average, Shift Share and No Change methods, the estimates for the 65+ experienced the highest error. When examining the model error results for the Ratio Change method, the 45-64 age group produced the highest error. These results suggest that age does have an impact on the accuracy of small area population estimates, although the effect of age differs between methods, both in the strength of the influence on error and in terms of which age groups are most greatly affected.

Overall, these results show that there are many factors such as age and the demographic composition of an area which may account for differences in error between data zones. These findings, therefore suggest that there is no one method which could be seen as the most accurate or best suited for producing small area population estimates in Scotland. Instead, results from this analysis indicate that each method will perform differently across the country, based on the demographics of each area, resulting in one method being the most appropriate in one place, while in another area, a different method will perform best. Using the results from the interaction model presented in Figure 5.3, this theory that the 'best' estimation method is dependent on place, will be tested using model error to compare methods for contrasting areas.

5.3.3: Case Studies

This section of the research will use the results of the interaction model, to create the predicted error for two contrasting case study areas. By modelling the error which could be expected in Scotland's largest and smallest data zones, it is possible to more fully demonstrate the differences between methods, and what these differences mean in reality. As this chapter seeks to further examine which method may be better suited to producing small area population estimates in Scotland, only the best performing methods, as shown in the previous analysis, were chosen for these case studies. As the simpler methods did not prove any more accurate than the No Change assumption, these approaches could be seen as having little worth. For this reason, only the Cohort Component, Ratio Change and Average methods will be examined from this point on.

<u>Case Study Area 1</u>

The first area of study is data zone s01002020, in the Marchmont East & Sciennes area of the City of Edinburgh. This is the smallest data zone in Scotland, covering an area of 12,367 square metres (GI-SAT, 2011) and according to the 2011 census had a population of 577. Using census data, to put together a demographic profile of this area, this data zone could be described as an urban, predominantly, young student area, with a majority of the population between the ages of 16-29, with over three quarters of the population falling within this age group, and over 70% of the population recorded as students. As well as appearing to be a student area with a young age profile, this area also had high levels of immigration and a large proportion of individuals living in communal establishments.

Figure 5.5: Data Zone s01002020 boundaries (Statistics.Scot.Gov, 2018)

Table 5.8: Predicted Model Error – Data Zone s01002020

	Cohort Component	Ratio Change	Average
0-15	13.09	7.20	7.53
16-29	9.64	5.29	5.51
30-44	13.62	6.03	6.89
45-64	10.98	5.37	5.76
65+	12.23	5.39	6.09
Total	**10.31 *(57)***	**5.41 *(30)***	**5.74 *(32)***

Table 5.8 shows the predicted errors for each of the complex methods by age group and by total population, with the implied number of individuals associated with each level of error in parenthesis. Results from this analysis show that the level observed for the population estimates for this area differ for each age group and for each method. Overall, for this area, the Ratio Change method appears to be the best performing method across all age groups, with lower levels of error compared to the other approaches. When looking at the total population error, calculated from converting the percentages to the number of individuals, it can be seen that the Cohort Component method had the highest level of error across all age groups with a total predicted error equating to 57 individuals. The Ratio Change and Average methods performed more similarly, with the level of error equating to 30 and 32 individuals respectively, with the Ratio Change method the best performing method in this area.

While it may be expected from the results of the regression model that the error would be highest for the 16-29 age group, this model error suggests that this is the age group most accurately estimated for all methods. This is likely, due to the high population of individuals in this age group. Results from the regression model also showed that population size had a negative influence on error, meaning that as the population of 16-29 year olds is so high in this area (440) compared to small populations of other age groups (e.g. 8 individuals aged 65+) the effect of population size counteracted any age influence in this area.

Case Study Area 2

The second area of study is data zone s01003915 in the Ross and Cromarty area of the Highlands. This area differs greatly from the first area, with this data zone the largest in Scotland, covering an area of 1,159 square kilometres (GI-SAT, 2011) and according to the 2011 census had a population of 764. The profile of this area is a rural, sparsely populated, with very low levels of immigration. In contrast with the first area, the age profile is more mixed, with only a small young adult population, with only 10% of the population falling into the 16-29 age group. The housing profile of this area also reflects its rurality, with very few people living in communal establishments and higher levels of unoccupied houses.

Figure 5.6: Data zone s01003915 boundaries (Statistics.Scot.Gov , 2018)

Table 5.9: Predicted Model Error – Data Zone s01003915

	Cohort Component	Ratio Change	Average
0-15	2.78	2.94	2.75
16-29	3.85	3.46	3.32
30-44	3.26	2.68	2.76
45-64	2.05	1.95	1.87
65+	2.57	2.13	2.17
Total	**2.67 *(20)***	**2.46 *(19)***	**2.39 *(18)***

Table 5.9 shows the predicted error for data zone s01003915. It can be seen from the results of the analysis that in this area, all methods produce estimates with a similar level of accuracy, with the error for the total population equating to between 18 and 20 individuals for all methods. Overall, the Average method produced the most accurate population estimates in this data zone, while the Cohort Component method was the least accurate, although the difference between the best performing and worst performing methods is negligible.

When comparing predicted error by age, it can be seen that the difference in error between each age group is in line with the results from the regression analysis, with higher levels of error predicted for the young adult age groups, and lower levels of error found for the 45-64 and 65+ age groups. This could be due to the more even age distribution in this area compared to the skewed age profile of the first case study area.

Comparing the model error for these two areas, some interesting differences emerge. When studying overall level of error, estimates were more accurate across all methods for the rural data zone in Ross and Cromarty compared to the

Marchmont East & Sciennes area. This may be expected due to differences in the demographic profiles of each area. The demographics of the population of the Marchmont East & Sciennes data zone feature much higher levels of a number of the area characteristics which were found in the regression analysis to increase estimate error, in particular in terms of age profile, levels of recent immigration and the proportion of the population living in a communal establishment. This is in contrast to the Ross and Cromarty data zone which had low levels of each of these variables. While two very contrasting areas were chosen for these case studies, the differences in predicted estimate accuracy found between these areas, highlights how area characteristics impact upon estimate accuracy and help illustrate how population estimates do not perform evenly across all small areas, but rather that some areas are more accurately estimated than others.

As well as demonstrating the effect that the demography of an area can have on the accuracy of population estimates, these predicted errors also show how one method is not necessarily consistently the best approach for all areas. When comparing the estimates produced for each case study area, results from this analysis reveal how the most accurate method also differs between areas, with the Ratio Change method producing the most accurate estimates in the Marchmont East and Sciennes area and the Average method performing the best in the Ross and Cromarty area. These findings support the theory discussed previously in this chapter, that there may not be one single method which is universally the best performing, but that, as a result of the demographics of an area, some methods are more appropriate in some areas compared to others.

5.4: BIAS

As well as evaluating the accuracy of population estimates based upon absolute levels of error, it is also important to understand the direction of error present in population estimates. While the previous sections of this chapter have only studied absolute error and how area characteristics may create higher levels of error for different methods, this section will examine the bias which may be present in population estimates. In order for population estimates to be used most effectively, some knowledge of the way in which estimates are wrong when error does occur is invaluable. Both population over and under estimates can be problematic depending on the how they are used and can have a widespread impact. Under-estimates are particularly harmful for local government users who may not provide adequate funding or infrastructure for their population, resulting in a strain on resources. On the other hand, in the private sector, over-estimates may be considered a greater problem in terms of over stocking supplies, resulting in a loss of profits. This suggests that in all cases, bias in population estimates should be explored in order to provide more detail regarding population estimate accuracy and to better inform users.

This section seeks to explore bias by comparing the most common error type (over-estimate, under-estimate or accurately estimated) for a range of areas and demographic groups, focusing primarily on the relationship between bias and settlement type, age and area deprivation. This extends the previous analysis to further examine the relationship between estimate accuracy and area characteristics from a different perspective and seeks to explore if a particular type of error is more common for some areas compared to others. Details of how bias was defined and calculated for the analysis in this section can be found in the Methodology and Data chapter. For the results presented in this chapter, the definition of “accurate” is defined as within 5% above or below the census population. Further analysis using narrower definitions of ‘accurate data zones’ can be found in the appendices.

5.4.1: Bias by age

The first demographic category which is explored in this section is age, as having knowledge of the population broken down by age is one of the most important features of a population estimate. As previous findings have suggested that age does have an influence on the accuracy of population estimates, analysis in this section will examine this further, looking beyond the extent to which age influences error, to exploring whether there are any differences in the direction of error for each age group.

Figure 5.7: Error bias by method and age

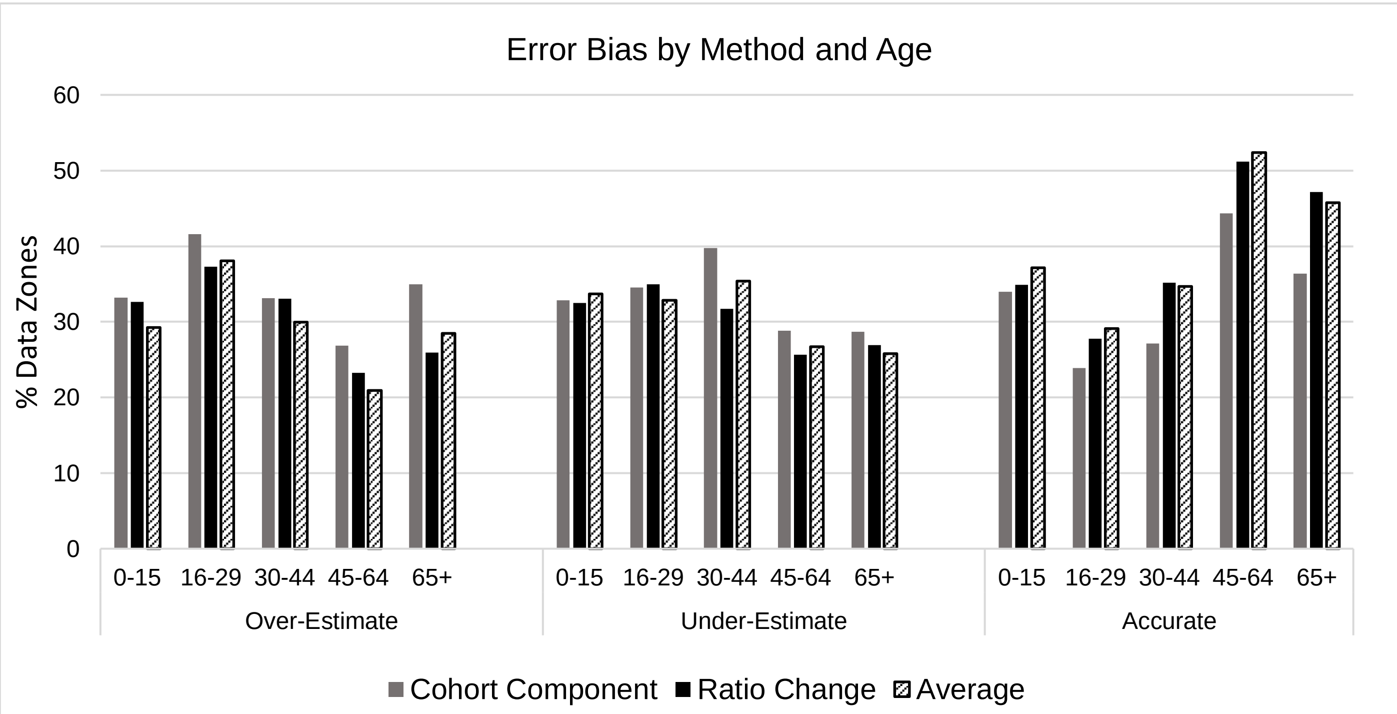


Figure 5.7 shows the distribution of the type of error for each age band and method. From this chart, it can be seen that for all methods, the 45-64 age group had the greatest number of accurately estimated data zones, while the 16-29 age group had the fewest. Across all age groups it can also be seen that the Cohort Component

method produced the fewest number of accurately estimated areas, with the Ratio Change method producing the most, with the exception of 30-44 age group where the Average method produced the greatest number of accurately estimated data zones.

From Figure 5.7, the direction of error can also be compared. First looking at the Cohort Component method, it can be seen that, for most age groups, there is a fairly even proportion of data zones over and under estimated, however for the 16-29 age group, the estimates were more likely to over-estimate the population, with 41.6% of estimates for this age group over-estimated compared to 34.7% which were under-estimated. When examining the alternative methods, it can be seen that for the Ratio Change method, there was very little difference between the proportion of data zones which were over and under-estimated, while the Average method was more likely to under-estimate the population of 45-64 year olds with 26.7% of areas under-estimated compared to 20.9% over-estimated.

These findings suggest that there is a difference in the type of error in the age specific population estimates between methods. A chi-square test of independence was carried out for each of the methods to examine the relationship between error type and age and this relationship was found to be statistically significant in each case. [Cohort Component, X2=884,64, df=8, p<0.00; Ratio Change, X2=1027.1, df=8, p<0.00: Average, X2=1048.7, df=8, p<0.00].

Using this chi-square analysis, it is possible to compare the distribution of error type for each method to the expected proportion of over, under and accurately estimated data zones, if there was no relationship between age and error. First, looking at the Cohort Component method, results from the chi-square analysis showed that, if no relationship between age and error type existed, the proportion of areas over, under and accurately estimated would be evenly distributed across age bands. Results from this analysis support the findings presented previously in this chapter, that the younger age groups are less likely to be estimated accurately compared to older age groups. The main findings from this section suggest that the two oldest age groups are disproportionately, accurately estimated, while the young adult age groups were disproportionately prone to error for all methods. When considering the direction of error, for all methods, there were a greater proportion of data zones both under-estimated and over-estimated than would be expected by chance for the 16-29 and 30-44 age groups, while for the two oldest age groups, the opposite was true. There were no clear instances of bias, with only the Cohort Component method estimates for the 16-29 age group having a substantially higher proportion of estimates over-estimated than under-estimated.

While these findings help to support results from earlier in this chapter regarding differences in accuracy between age groups, there is little evidence of significant bias, with similar proportions of areas under and over-estimated for each age group.

5.4.2: Bias by Settlement Type

In addition to examining the bias in error for age groups, it is also important to explore if any bias exists between settlement types. It is reasonable to believe that population estimates may vary between settlement types, based upon the differing characteristics of these areas. McCrone (2017:85) explains, "In truth, there is no single "*Scottish" pattern of demography, for Scotland is a highly diverse country and there are 'multiple Scotlands'. For example, the changes in the islands and above the highland line are not the same as the lowlands of Scotland, neither are they entirely independent from them.".*

Understanding the distribution of Scotland's population has been a growing area of interest and concern in recent years. The way in which Scotland's population is spread has resulted from many historical processes and events, from the Highland Clearances which forced people from their homes in the North and which have never been re-populated, to the industrial revolution which drew people to the densely populated Central Belt. Recent figures released by NRS show that in Scotland 90% of the population live on 2% of the landmass (NRS, 2018). While 98% of the land in Scotland is classed as rural, it only contains 18% of the total population. These figures help to provide an insight into the dispersed nature of Scotland's rural population (Scottish Government, 2015). In recent years, there has been a growing concern for these rural communities with fears of de-population. Hopkins and Copus (2018:2) describes these fears: "*Scotland's Sparsely Populated Areas have a demographic legacy which means it faces decades of demographic decline and in particular a shrinkage of its working age population*". As a result of these concerns, it is important to not only assess the accuracy of population estimates for different settlement types, but also the bias which may exist. In particular reference to rural Scotland, any bias may mean that population decline could be more advanced than previously feared or not as substantial a problem as thought. In order to explore if bias in population estimates exists when data zones are organised into settlement types, the Scottish Government's six-fold Urban Rural classification system is used in this study.

Figure 5.8: Error Bias by Settlement Type

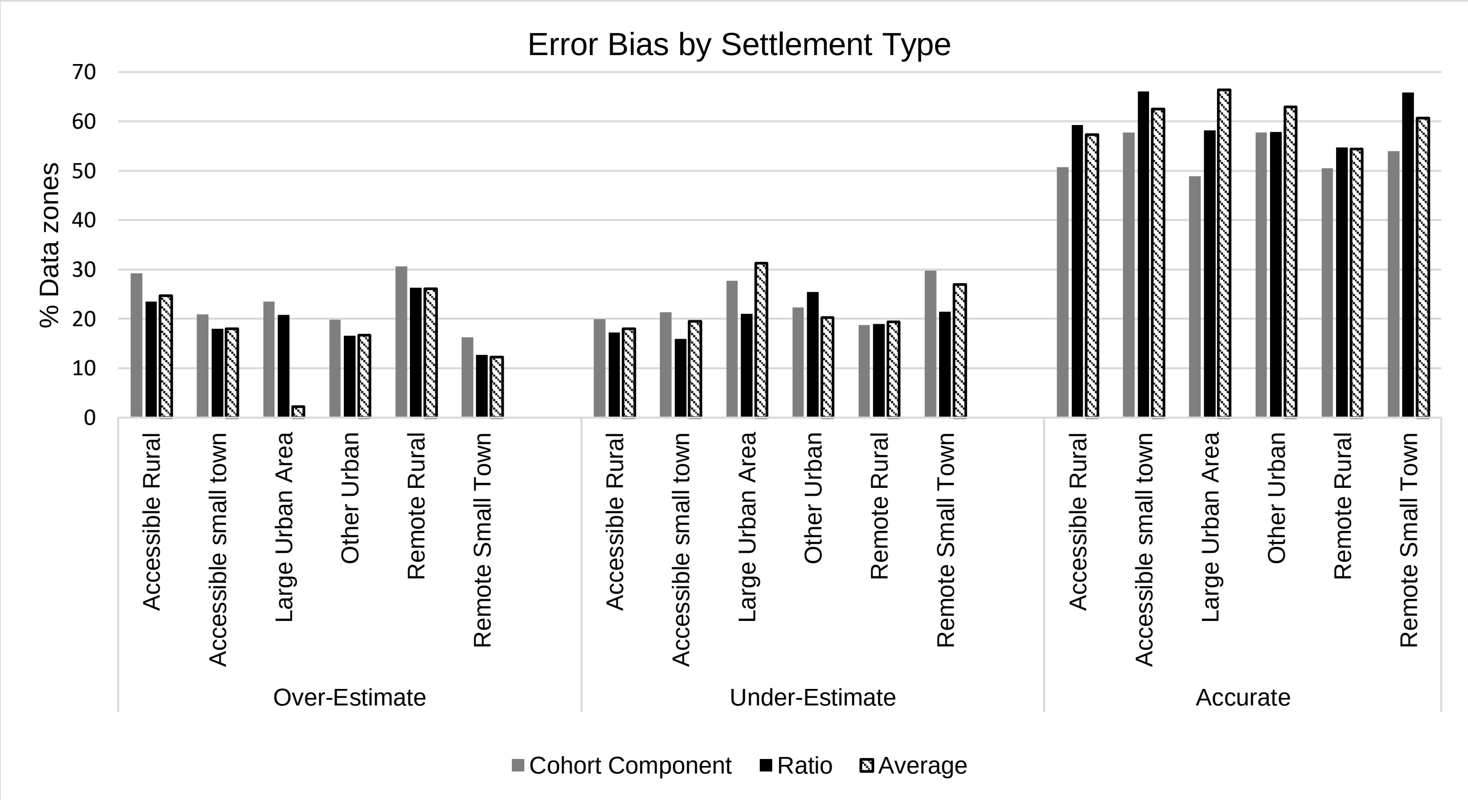


Figure 5.8 shows the distribution of error classification for the Cohort Component, Ratio Change and Average methods by settlement type. First, looking at the results for the Cohort Component method, it can be seen that, in most cases, a majority of the data zones were classed as accurate for each settlement type. The only settlement type where less than 50% of the data zones were classed as accurate was for large urban areas. When examined in more detail, it was also found that large urban areas not only have the fewest number of accurately estimated data zones but they were also prone to the most extreme errors. Of the ten data zones with the highest over–estimates, seven were located in large urban areas, while five of the ten most under-estimated data zones were also located in large urban areas.

When a chi square analysis was carried out to examine the relationship between settlement type and Cohort Component error bias in more detail, a statistically significant relationship was found ($X2=93.1$, $df=10$, $p<0.00$). Looking at the proportion of accurate data zones, it was found that Other Urban areas, Remote Small Towns and Accessible Small Towns had a greater proportion of accurate data zones than would be expected by chance (53.20%) while the Large Urban areas, Accessible Rural areas and Remote Rural areas had fewer than expected.

Exploring the accuracy of Accessible Rural and Remote Rural areas further, it was found that in both cases, around half of the data zones in these areas were classed as accurate with 50.88% of data zones in Accessible Rural and 50.57% of Remote Rural areas classed in this way. Of those data zones which were not classed as accurate, it was found that for both types of rural settlements, there was a greater number of data zones over-estimated than under-estimated. For Accessible Rural areas, it was found that 29.69% of data zones were over-estimated while 19.43% were under-estimated. These findings were similar for Remote Rural areas where 31.35% of data zones were over-estimated and 18.08% were under-estimated. Comparing these figures with the expected over and under estimate values derived from the chi square analysis, it was found that for both rural settlement types, there were a greater number of over-estimated data zones than expected and fewer under-estimated data zones than expected. Of all the settlement types, only the rural settlements had more data zones which were over-estimated than under-estimated, with all other settlement types having a greater or equal number of under-estimated data zones.

When comparing these findings to the population estimates produced using alternative methods, Figure 5.8 shows that there are differences in the performance of the methods across areas. A chi square analysis was again carried out to explore the relationship between error and settlement type for the Ratio Change and Average methods. In both cases, the relationship was found to be statistically significant (Ratio Change method, X2= 71.16, df= 10, p < 0.00, Average method, X2=66.46, df= 10, p < 0.00). This analysis allows further exploration of the differences in the performance of methods across settlement types.

Results of this chi square analysis shows that the Ratio Change and Average methods performed in a similar way to the Cohort Component method, with fewer accurate data zones than expected for the Large Urban, Remote Rural and Accessible Rural areas, a greater number of over-estimated data zones and fewer under-estimated data zones for these same areas.

These findings suggest that there is a relationship between error bias and settlement type, with some areas more likely to be over-estimated and others under-estimated. The case study areas examined earlier in this chapter already illustrated how error differed between urban and rural data zones in two particular areas, however this additional analysis suggests that area type not only has an influence on the margin of error present in population estimates but also the direction of that error.

5.4.3: Bias by Deprivation

In addition to age and settlement type, it is also important to examine whether there is any bias present when the population is broken down by deprivation level. As previously discussed, population estimates are most commonly used by local government and planners to allocate resources and funding, and for this reason, it is important to understand whether there is any bias in population estimates towards more or less deprived areas, to ensure that all areas are receiving the resources they require.

To classify areas according to deprivation level, the 2009 Scottish Index of Multiple Deprivation has been used to divide the data zones into deciles based upon their rank, with decile 1 indicating the most deprived data zones and decile 10 the least deprived.

Figure 5.9: Error bias by SIMD Decile

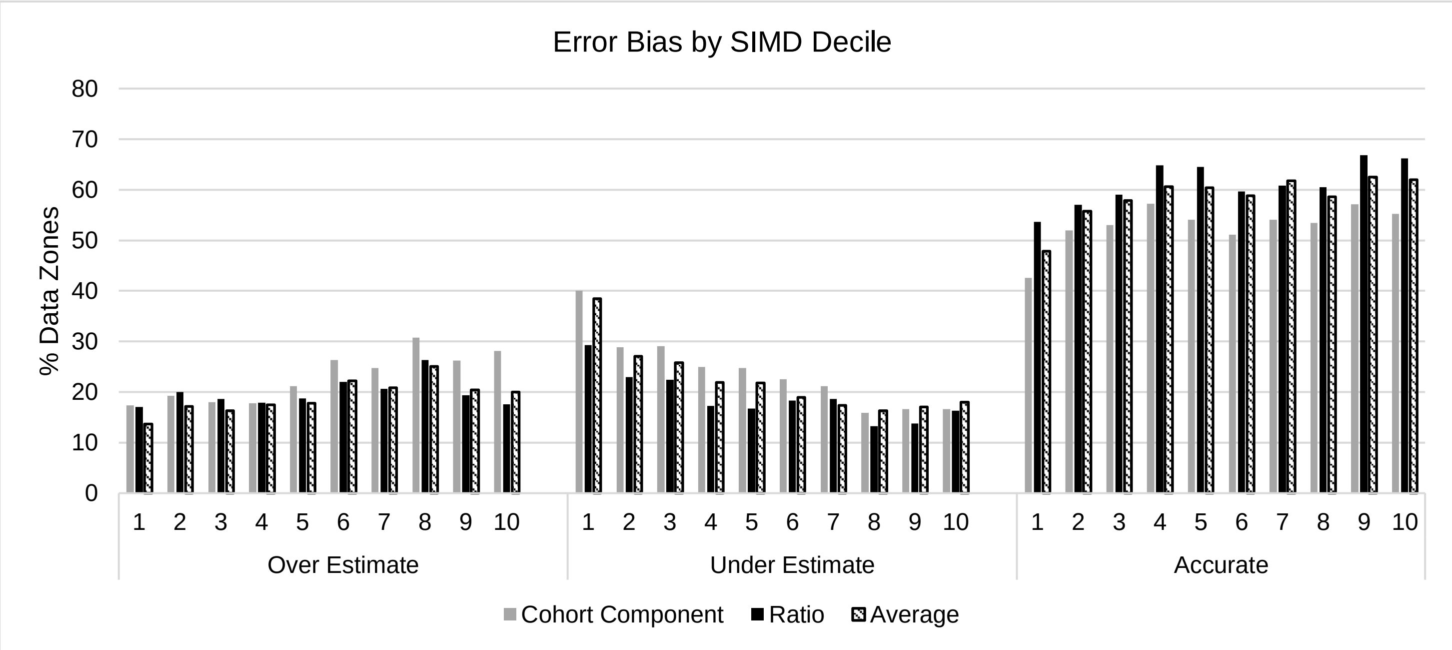


Figure 5.9 shows the error bias by SIMD Decile, by method. First looking at the Cohort Component method, it appears that there is a clear split between the most and least deprived areas. It can be seen that the most deprived decile had the fewest number of accurately estimated data zones, and was the only decile where fewer than half of the data zones were classed as accurate. This decile also had the highest proportion of under-estimated data zones, with 40% of estimates for these areas lower than the true population size compared to 17.38% which were over-estimated. This is the opposite of the findings from decile 10, where there appears to be a bias towards over-estimation, with 28.0% of data zones over-estimated compared to 15.38% under-estimated.

Figure 5.10: Bar Chart showing over/under estimate error by SIMD decile for the Cohort Component method.

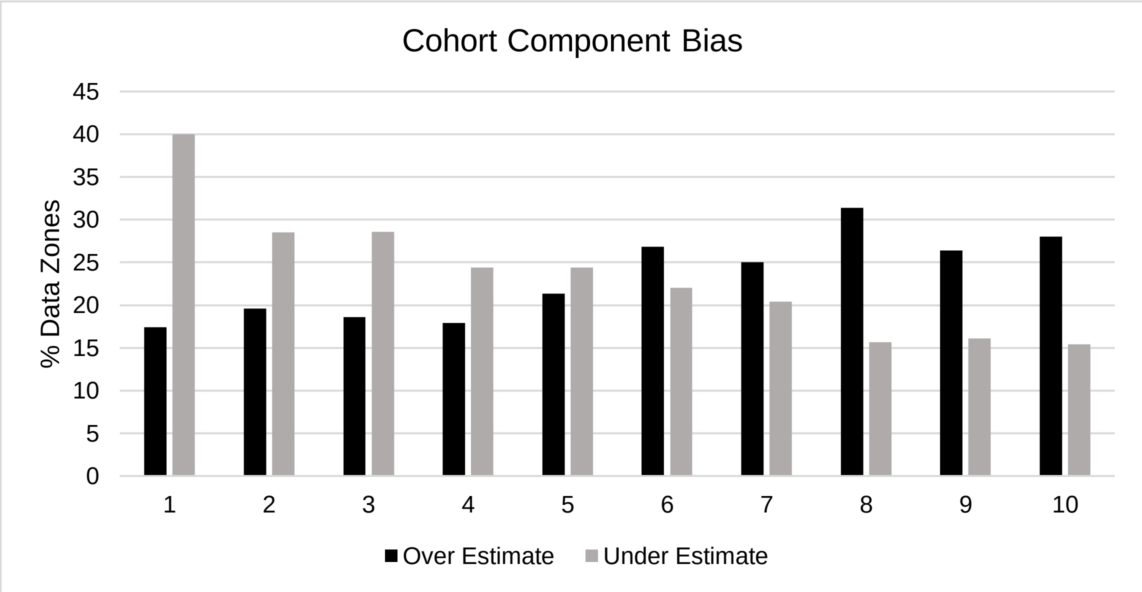


Figure 5.10 explores this trend in bias further. When the proportion of under and over-estimated data zones are compared across all deciles, it can be seen that there appears to be a clear split between the deciles 1-5 (the most deprived areas) and deciles 6-10 (the least deprived areas). In deciles 1 to 5, Figure 5.10 shows that there is a greater number of under-estimated data zones than over-estimated. This finding is reversed in deciles 6-10 where the number of over-estimated data zones outnumber the under-estimated data zones. This does not appear to be a linear relationship, as there is not a continuous decline of under-estimated data zones as areas become less deprived or a steady increase in over-estimated data zones as deprivation decreases. However, it does appear to be a consistent finding, with an interesting shift between deciles 5 and 6.

The relationship between error bias and deprivation was explored further using a chi square analysis and the results were found to be statistically significant (X2= 224.22, df = 18, p<0.00).

Table 5.10: Percentage of data zones over, under and accurately estimated by SIMD Decile with expected values derived from the chi-square test (Cohort Component Method).

	Accurate (%)	Over (%)	Under (%)
Decile			
1	42.62	17.38	40.00
2	51.93	19.57	28.51
3	52.84	18.59	28.57
4	57.72	17.90	24.38
5	54.22	21.35	24.42
6	51.16	26.81	22.03
7	54.53	25.04	20.43
8	52.92	31.38	15.69
9	57.45	26.42	16.13
10	56.62	28.00	15.38
Expected	**53.20**	**23.25**	**23.55**

As the deciles are created by dividing the data zones into ten equal categories based upon SIMD rank, if there were no relationship between deprivation and error type, it would be expected that there would be the same proportion of data zones which were over, under and accurately estimated for each decile. However, Table 5.10 shows that the distribution of error type not only differs between deciles, but each decile differs from the expected values. Although “accurate” was most common error type found for each of the deciles, there is a greater tendency for populations to be underestimated in the most deprived areas while the populations from the least deprived areas were more likely to be overestimated. Findings from the chi square test support the descriptive findings from Figure 5.10, with more data zones in deciles 1-5 consistently under-estimated than expected while decile 6-10 all had more data zones over-estimated than expected.

This is an important finding as it suggests that more deprived areas are being consistently under-estimated, particularly in the most extremely deprived areas. The under-estimation of a population can be considered more problematic than an over-estimation as it means that an area may not be getting adequate funding or enough resources for the population. It therefore follows that the under-estimation of more deprived areas and the over-estimation of the least deprived areas may be leading to the misallocation of resources, possibly resulting in the entrenchment of existing inequalities.

In order to find out whether this under-estimation of more deprived areas is inherent in other population estimation methods, analysis was also conducted for the Ratio Change and Average methods. Again a chi square test was conducted for both the Ratio Change (X2=108.48, df = 18, p<0.00) and the Average method (X2=194.76, df = 18, p<0.00), both of which were found to be significant.

Table 5.11: Percentage of data zones over, under and accurately estimated by SIMD Decile with expected values derived from the chi-square (Ratio Change and Average methods)

	Ratio Change			Average		
	Accurate (%)	Over (%)	Under (%)	Accurate (%)	Over (%)	Under (%)
Decile						
1	53.85	18.77	27.38	50.15	16.77	33.08
2	58.71	18.95	22.34	56.55	19.26	24.19
3	58.83	19.20	21.97	60.52	17.20	22.27
4	64.97	18.36	16.67	62.50	18.83	18.67
5	62.98	20.58	16.44	61.29	20.43	18.28
6	59.01	23.73	17.26	58.86	24.81	16.33
7	62.06	22.58	15.36	62.52	21.97	15.51
8	61.38	26.46	12.15	60.62	27.54	11.85
9	64.82	22.58	12.60	65.44	23.20	11.37
10	65.85	18.77	15.38	63.23	24.31	12.46
Expected	**61.25**	**21.00**	**17.75**	**60.17**	**21.43**	**18.40**

Table 5.11 shows the percentage of data zones over, under and accurately estimated by decile for the Ratio Change and Average methods. There are some similarities between these findings and those from the analysis of the Cohort Component method. Like the Cohort Component method, the first decile had a lower proportion of accurately estimated data zones compared to the expected values for both the Ratio Change and Average methods. As well as the number of accurate data zones, this analysis also found that for the Average method, the same split between the top five most deprived and the five least deprived deciles found for the Cohort Component method also existed. However, this split was not found in the analysis of the Ratio Change estimates. While the first decile has a high number of under estimated and a lower number of accurately estimated data zones compared to what would be expected, there is little variation between other deciles and the expected values.

This finding that the most deprived decile consistently had more under-estimated data zones than would be expected, with the difference between the actual and expected values larger for the first decile than any others, suggests that this trend is not unique to the Cohort Component method and would still occur regardless of a change in methodology. This thesis therefore identifies wider methodological issues that span across methods that require attention in order that resource allocation, across areas and deprivation levels, are better addressed.

Overall, this analysis reveals some interesting results, and provides a greater insight into the error which is present in population estimates for different demographic categories. The models give users an indication of how much error they might expect in population estimates and the direction of error. As discussed, to use population estimates effectively, it is important not only to understand the amount of error which is present but also the direction of the error. While it was found that there was some bias present in the estimates produced using the Cohort Component method, with differences found in the amount of under and over-estimated data zones for age groups, settlement types and levels of deprivation, further comparison of these estimates to others produced using alternative methods found similar levels of bias. This suggests that while population bias is an important problem that can have harmful effects on the provisions allocated to certain areas, it is not an issue which is limited to one particular method, but is to do with the demographic composition of these areas. This may mean that while bias may be difficult to overcome, informing planners and policy makers of any potential bias, may help them allocate resources more fairly and effectively.

5.5 CONCLUSION

In this chapter, the small area population estimates produced by the Cohort Component method have been evaluated in a number of ways both in terms of their performance in their own right and in comparison to other available methods. The findings from the analysis conducted in this chapter have produced a number of interesting results which may raise the question of whether the Cohort Component method is the best method for producing small area population estimates in Scotland.

These findings suggest that the Cohort Component method produced more accurate population estimates when compared to the simpler methods available such as the Shift Share and Constant Share methods. However, it was also found that the complex methods (the Ratio Change and Average method) produced more accurate estimates than the Cohort Component method. Not only did the findings show that the Ratio Change and Average methods were more accurate overall, but were also more accurate for each age group. While the analysis from the multilevel models found that the Average and Ratio Change methods had a lower level of error compared to the Cohort Component method, when bias was explored, there was very little difference between methods, with all approaches having similar patterns of bias in most cases.

Overall, when considering all the results from the research carried out in this chapter it does appear as if more accurate, small area population estimates would be produced using either the Ratio Change or Average methods rather than the Cohort Component method currently in use in Scotland. However, while the estimates produced may be more accurate, the additional work in acquiring suitable datasets, and in the case of the Average method producing two sets of estimates, may mean the increased time and resources required to produce these methods, outweighs the benefits of lower levels of error. In order to reach a firm conclusion regarding the most appropriate method for producing Scotland’s small area population estimates, more discussion is needed to weigh the costs and benefits of each approach.

Chapter 6: Evaluating Small Area Population Projections

6.1: INTRODUCTION

In addition to evaluating the accuracy of population estimates, this research also examined the accuracy of population projections, which provide demographic data for future years. While population estimates are a useful tool for planning and policy making, they cannot be used to inform longer term decision making; this is where projections provide valuable data regarding how the population will change in the future, if past observed trends in population change continued. While the population estimates and projections can be produced using some of the same methodological approaches, they differ both in terms of what they show and how they are used. Smith et al (2013:3) explain that, "*This distinction* [between estimates and projections] *is based on both temporal and methodological considerations. The most fundamental difference is that projections refer to the future whereas estimates refer to the present or the past".* For this reason, both population estimates and projections were evaluated in their own right, in order to fully assess the performance of the methodologies which can be used to produce each of these population statistics.

Evaluating population projections is particularly important in the Scottish context where the production of sub-council level population projections is limited, and the recent endeavour by NRS to create these projections, is the first project of this type in the UK. While population projections in Scotland are generally produced for higher levels of geography, in 2016, NRS released one-off, experimental, 2012- based sub-council population projections. As this was a one-off release, there has been little evaluation of how well the NRS small area population projection methodology captures the changes in Scotland's population at a local level, or of the alternative methodological approaches which could be used to produce them. In order to provide an insight into the 'accuracy' of these projections, the Cohort Component method used to produce these experimental statistics was used in this research, to establish historical population trends between 2001 and 2006 and create a five-year projection spanning from 2006 to 2011. This end date of 2011 allows the projected population to be compared to the census population figures for the same year. As population projections only provide the future population size and composition if trends continue, rather than being informed by possible future changes in policy and global events, it would be unfair to describe them as accurate or incorrect. However, by examining the discrepancy between the projected and actual populations, it provides the opportunity to analyse the differences between areas and demographic groups, and to explore which area characteristics may play a role in influencing the difference between the projection and the truth. Longer projections were also produced for this research, covering an eight-year period from 2006 to 2014, the results of the analysis carried out for these longer projections can be found in the Appendices.

This chapter consists of three analysis sections, each evaluating small area population projections from a different perspective. The first of these analysis sections follow a similar structure to that found in the previous chapter, first evaluating the Cohort Component method in its own right as the dominant approach in section 6.2, before comparing this method to simpler methods which may prove easier for local users to apply, in section 6.3. This analysis revealed some interesting results, with some evidence found to suggest that simpler methods can produce small area population projections to a similar degree of accuracy to the Cohort Component method. These simpler methods could therefore, provide a credible alternative to the Cohort Component method for local users who took part in this research and indicated their desire to produce their own population projections but may not have access to resources required for the Cohort Component method. The final analysis section in this chapter (6.4) examines the way in which the performance of each projection method changes over the projection period, looking at the relationship between error and length of projection as well as how far a projection can span, while still being useful for planners and policy makers. This issue is particularly relevant when taking into account responses given by participants who took part in this research, whose expectations of accuracy for long term projections will be explored in further detail in Chapter 7.

6.2: THE COHORT COMPONENT METHOD

Following the same approach taken to evaluating the population estimates in the previous chapter, the Cohort Component method will first be assessed in isolation before comparing this method to alternative approaches. As described previously with reference to population estimates, the Cohort Component method is a widely used approach in the production of population projections, with Smith et al (2013:45) describing *“that 89% of states that make state-level projections of total population use some form of the cohort-component method; for states that make projections by age, sex, and race, 95% use the cohort-component method”*. With Smith et al (2013) going on to describe the Cohort Component method as a ‘flexible and powerful approach to population projection’, it is clear why this method is favoured by so many. This section of the analysis seeks to evaluate how well this Cohort Component method performs for small areas in Scotland and explores which demographic factors may influence the ‘accuracy’ of projections produced using this method.

6.2.1: Descriptive Statistics

Table 6.1: Range of APE (Cohort Component Method)

	Min.	Max.	Mean	Standard Deviation
0-15	0.03	88.49	5.68	7.31
16-29	0.00	35.50	6.27	5.75
30-44	0.00	23.74	5.29	4.23
45-64	0.00	10.63	2.30	2.04
65+	0.04	15.83	3.32	2.85
Total	**0.02**	**17.04**	**2.91**	**2.42**

Table 6.1 shows the distribution of “error” present in the population projections produced using the Cohort Component method for the final year of the projection in 2011. These descriptive statistics show that, on average, the 16-29 age group produced the highest level of “error”, while the lowest level of error was found for the 45-64 age group. Interestingly, it can also be seen from these results, that the average error produced for the 45-64 age group (2.30%) was lower than the average error found for the total population projection which was found to have an average error of 2.91%. This was the only age group where the average “error” was below average for the total population. While on average, the least “accurate” projections were produced for the 16-29 age group, the single highest level of “error” was found for the 0-15 age group where an error of 88.49% was found in the Anderson/City area of Glasgow. In this area, the projection produced a population of 3,325 0-15 year olds while the census recorded only 1,764 individuals of this age. Overall, the figures in Table 6.1 indicate that the projections for the younger age groups produced higher levels of “error” compared to the older (45-64 and 65+) age groups, both in terms of average error and when looking at maximum “error”.

As with the results of the analysis carried out in the previous chapter examining population estimates, these findings presented in Table 6.1 suggest that age has an influence on the performance of population projections, with higher levels of “error” found for some age groups compared to others.

6.2.2: Exploring Area Characteristics

In order to explore the theory that age may have an impact upon projection “accuracy” and to explore the potential influence that other demographic factors and area characteristics may have upon “error”, regression models were used to try and explain why differences in “accuracy” may occur. In order to evaluate both the population estimates and projections produced by the Cohort Component method equally and fairly, the same area characteristic variables which were used in the analysis presented in the previous chapter, will also be used in the analysis in this chapter.

In the previous chapter which evaluated the population estimates produced using the Cohort Component method, the impact of area characteristics was explored using a linear regression model. However, as multiple projections were produced for each SCAP area for multiple years, in this case, a multilevel regression model (structured with years nested within areas) was deemed more appropriate.

Table 6.2: Multilevel Regression Model

	Coefficient	Std. Error	Sig.
Intercept	0.53	0.03	<0.01
Arrived within a year (International Migration) (%)	0.09	0.03	0.01
Communal Population (%)	0.03	0.00	<0.01
Non-White (%)	0.01	0.01	0.33
One Person Household (%)	-0.01	0.00	0.06
Overcrowding (%)	0.03	0.01	<0.01
Population Growth (%)	0.00	0.00	0.01
Population Size	0.00	0.00	<0.01
Students (%)	-0.01	0.01	0.25
Unemployed (%)	-0.04	0.02	0.03
Unoccupied Housing (%)	0.02	0.02	0.25
Age (Reference 0-15)			
16-29	0.07	0.03	0.01
30-44	-0.10	0.03	<0.01
45-64	-0.60	0.03	<0.01
65+	-0.55	0.03	<0.01
Year of Projection (Reference, Year 1)			
Year Two of Projection	0.30	0.03	<0.01
Year Three of Projection	0.50	0.03	<0.01
Year Four of Projection	0.68	0.03	<0.01
Year Five of Projection	0.87	0.03	<0.01

Table 6.2 shows the results of the multiple regression model exploring the relationship between area characteristics, age and year of projection, and “error”. It can be seen from these results that, as with the population estimates, age and area characteristics were found to have an influence on the “accuracy” of population projections, however there were some differences in these findings, compared to those from the population estimate analysis.

First, looking at the effect of age, it can be seen from Table 6.2 that only the 16-29 age group was associated with higher levels of error compared to the 0-15 age group; suggesting that this was the only age group where projections were less “accurate” than the 0-15 age group, while the projections for all other age groups were more “accurate”. This differs from the results from the population estimates where the 30-44 age groups were also found to increase error compared to the 0-15 age group. This may suggest that population projections produced for the 0-15 age group may be more prone to “error” compared to the population estimates. One reason for this, may be difficulties associated with projecting forward the fertility rates of each area. When producing population projections using the Cohort Component method, the past trends for each of the drivers of population change (fertility, mortality and migration) must be continued into the future. The results from this research may suggest that the projecting forward of fertility rates may not capture true changes in the birth rate. As discussed in Chapter 2, there are many factors which can influence the fertility rate, including economic factors, changes in women's engagement with higher education and the labour market, and levels of migration. These issues make it difficult to successfully produce assumptions regarding changes in the fertility rate.

When exploring the impact of year of projection on “error”, there is a clear positive relationship between each year of the projection and “error”, with results from this model suggesting that the “accuracy” of the projections steadily decreases as the projection period continues. These findings would be expected, with the projection years closest to the launch year more “accurate” compared to the projections for several years into the future.

Finally, when examining the impacts of area characteristics, there are also some differing results compared to the population estimate analysis. Some of the results from this analysis are to be expected and in line with results presented in Chapter 5; such as higher levels of immigration, and population growth both having a negative influence on “accuracy”, and increases in the population size associated with lower error. However, some of the results were more surprising. In particular, the results which suggest that there is a negative relationship between “accuracy” and variables such as unemployment; with this model suggesting that as the percentage of this variable increases, projections become more “accurate”. In addition to this, there were other variables included in this model which appeared to have no significant impact on “error” such as the percentage of students and ethnic minority population, which could also be seen as surprising. One reason for this may, be due to the size of the areas which are the subject of this analysis. While the population estimate analysis dealt with data zones which could be extremely small geographies, with only between 500 and 1000 individuals, population projections are produced for larger sub-council (SCAP) areas, typically defined as multimember wards or geographies of equivalent sizes. This may mean that, compared to the population estimate analysis, the proportion of each of these area characteristics is less concentrated, and the demographics of these larger SCAP areas more diverse. These more mixed areas may mean that it is less likely that there are meaningful quantities of each of these variables present in each area, reducing their impact on projection “accuracy”.

These findings may suggest that although there is some evidence that area characteristics do have an impact upon the “accuracy” of small area population projections, it may be difficult to effectively pinpoint the particular demographic factors which may contribute to increased level of “error” in some areas. This is a finding which is supported to some degree by previous research, with a similar project conducted by Wilson and Rowe (2011) which attempted to answer the question; ‘To what extent can forecast errors be predicted on the basis of local area characteristics?’ concluding that error in population projections could only be anticipated using area characteristics to ‘some extent’. This conclusion could also be applied to the findings of this evaluation of the Cohort Component projections where, while some factors, in particular age and year of projection, were found to be a predictor of projection "error", when using individual area characteristics to produce a predicted error, the results may be limited.

In order to explore the influence of area characteristics on projection "error" in more detail, a model error was produced to demonstrate the effects of the statistically significant percentage variables.

Figure 6.1: Cohort Component Model Error[10]

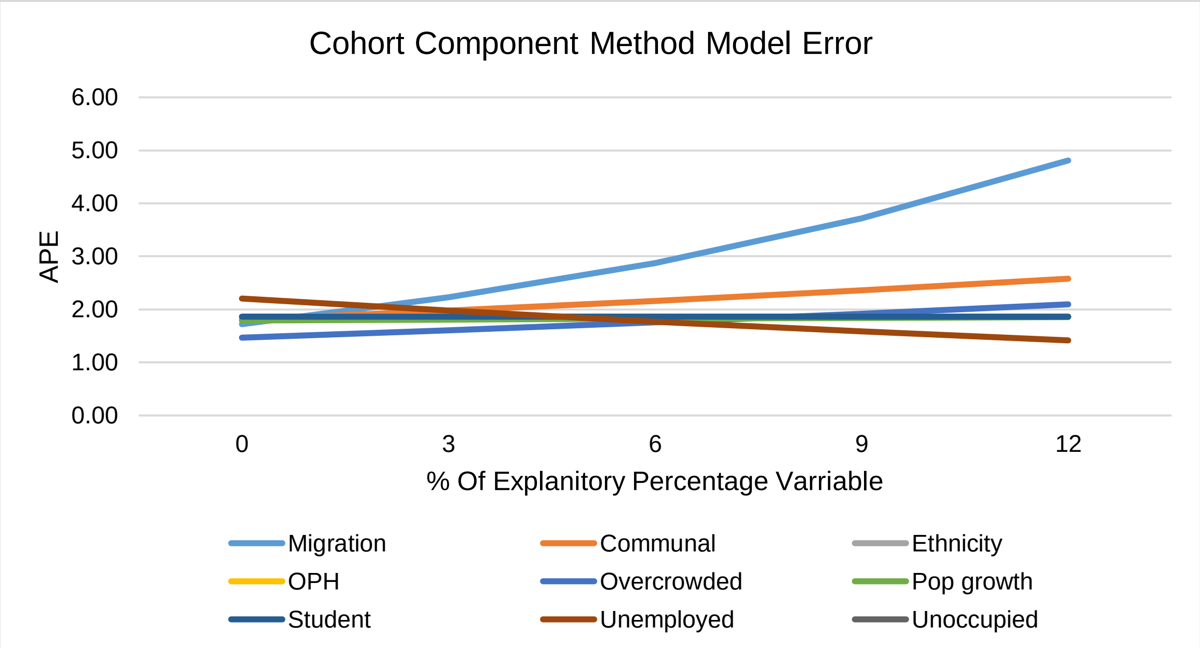


Figure 6.1 shows how the "error" present in the population projection increases for 30-44 year olds for year three of a projection for an average area, as each of the variables increase from 0 to 12%. It can be seen from this model error that most of these area characteristics only had a modest impact on "error", with a difference of less than 1% over the increase of each area characteristic, with the exception of the Arrived Within a Year variable. Figure 6.1 clearly shows that for this variable, the level of "error" increases more rapidly compared to other area characteristics in this model, with the "error" increasing by 3.09% as the proportion of individuals who have arrived within a year increases by 12%.

[10] Range of Variables in Dataset

- % Communal Population = 0 – 12.24 (mean : 1.04%)
- % Students = 2.54 – 47.5 (mean : 7.35%)
- % Unoccupied Housing = 0.9 – 5.98% (mean : 2.68%)
- % Unemployed = 1.20 – 8.85% (mean : 4.56%)
- % Population Growth = 0.10 – 75.92% (mean : 13.60%)
- % One Person Households = 17.97 – 53.92% (mean : 33.56%)
- % Non-White Population = 0.43 – 35.50 (mean : 3.27%)
- % Arrived within a Year = 0.04 – 13.45% (mean : 0.93%)
- Age band = 30-44
- Average Population Size = 3558
- Year of Projection = 3 (2009)

The findings from this model may suggest that, as discussed previously with reference to the higher levels of “error” for the 0-15 age group, the approach taken by the Cohort Component method, to project forward each element of the ‘population equation’, may influence its performance. In this case, the results from this model error suggest that migration assumptions used in these projections did not match what happened in reality over the projection period. Bearing in mind that these projections simply continue past trends and do not make predictions of how the population will change in the future, there is very little that can be done to counter this potential for “error”. However, these results do highlight how some elements of population change, particularly large scale or very area specific changes, may not be captured in past trends.

In order to explore this approach of projecting forward each element of population change more fully, the Cohort Component method will be compared to alternative methods. As with the Cohort Component method, these alternative projections are based upon the continuation of past population trends, however, they differ in the fact that they use the change in the population counts, rather than changes in births, deaths and migration. By comparing the Cohort Component method to these simpler approaches, it may be possible to explore whether this more complex approach, considering all elements of population change, results in more “accurate” projections, or opens the method up to potential higher levels of “error”.

6.3: COMPARISON TO ALTERNATIVE PROJECTION METHODS

This section will explore the performance of a series of alternative methods compared to the Cohort Component method. As discussed in the previous chapter when comparing estimation methods, it is important to compare the levels of “error” found in a range of methods in order to fully contextualise the “accuracy” of the projections produced using the Cohort Component method. While population projections by their nature will never give a fully accurate indication of the future population, due to the infinite unforeseeable events which could influence population size and structure, particularly at sub-council levels of geography, by comparing a series of projections produced using different methods, it can give some indication of the level of “error” which may be expected from small area population projections.

In this research, the Cohort Component method will be compared to three simpler projection methods. All the alternative methods in this section of the study are simple extrapolation methods; the Arithmetic, Exponential and Geometric methods, and only require two data points to produce projections rather than the multiple data sources required for the Cohort Component method. By comparing population projections produced using the Cohort Component method to these simpler methods, this analysis will not only provide greater context to aid the evaluation of the Cohort Component method, but also provide an insight into whether simpler methods which are less data and resource intensive could be a realistic alternative to the currently favoured approach for producing small area population projections in Scotland. As with the population estimates, the methodology used to produce each of these alternative projections can be found in the Methodology and Data Chapter.

6.3.1: Descriptive Statistics

Table 6.3: Range of APE: All Methods

		Min.	Max.	Mean	Standard Deviation
Cohort Component Method	**0-15**	0.03	88.49	5.68	7.31
	16-29	0.00	35.50	6.27	5.75
	30-44	0.00	23.74	5.29	4.23
	45-64	0.00	10.63	2.30	2.04
	65+	0.04	15.83	3.32	2.85
	Total	**0.02**	**17.04**	**2.91**	**2.42**
Arithmetic Method	**0-15**	0.00	103.06	7.42	9.17
	16-29	0.06	54.78	7.23	6.72
	30-44	0.06	24.26	7.19	5.16
	45-64	0.00	14.17	3.39	2.68
	65+	0.06	13.91	4.01	2.84
	Total	**0.00**	**18.61**	**3.10**	**2.84**
Geometric Method	**0-15**	0.07	133.67	7.19	10.75
	16-29	0.06	80.49	7.50	7.45
	30-44	0.05	24.98	7.18	5.28
	45-64	0.02	14.14	3.75	2.85
	65+	0.08	15.88	4.01	2.97
	Total	**0.03**	**18.27**	**3.10**	**2.78**
Exponential Method	**0-15**	0.07	133.67	7.19	10.75
	16-29	0.06	80.49	7.50	7.45
	30-44	0.05	24.98	7.18	5.28
	45-64	0.02	14.14	3.75	2.85
	65+	0.08	15.88	4.01	2.97
	Total	**0.03**	**18.27**	**3.10**	**2.78**

Table 6.3 shows the range of "error" found in the alternative projections created using simpler methods. These alternative projections performed similarly to one another, with the Exponential and Geometric methods producing the same population figures despite the different processes used to produce the projections. This is explained by Smith et al (2014:208) who states that, *"When they* [population projections] *have the same base year and launch year, projections for areas with slow or moderate growth rates often fall within a fairly narrow range".* It can be seen from these descriptive statistics that, on average, these simpler methods did not perform as well as the Cohort Component method. This is true not only for the total population, but also for each age group. While these simple methods do not appear to produce more "accurate" projections compared to the Cohort Component method,

the pattern of “error” between age groups largely mirrored that found for the Cohort Component method. Across all the projection methods included in this study, the lowest average “error” was found for the 45-64 age group and, with the exception of the Arithmetic method, the 16-29 age group was found to have the highest average “error”. As observed for the Cohort Component method, the projection for 0-15 year olds in the Anderson/City SCAP area of Glasgow had the highest level of “error” for all of the simple methods. This further suggests that area characteristics may play an important role in influencing projection “accuracy” with some areas more difficult to project than others.

In addition to examining the accuracy of the population projections in the final year, it is also important to assess their accuracy across the whole of the projection period. In this analysis, the adjusted population estimates were used as the ‘true’ population, as explained in Chapter 4.

Figure 6.2: Average Absolute Percentage “Error” for Total Population over Projection Period

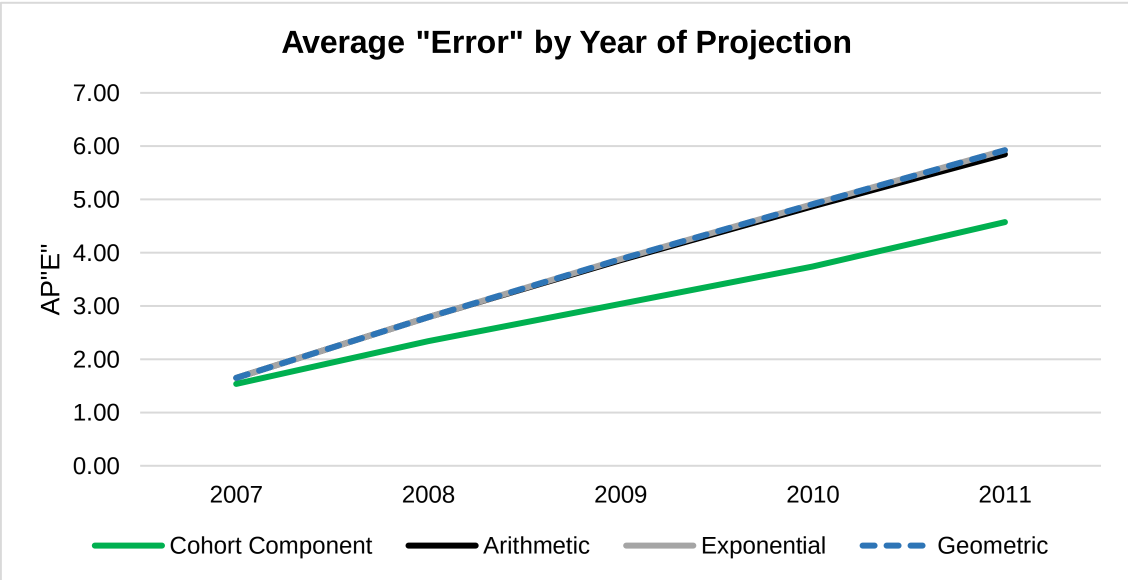


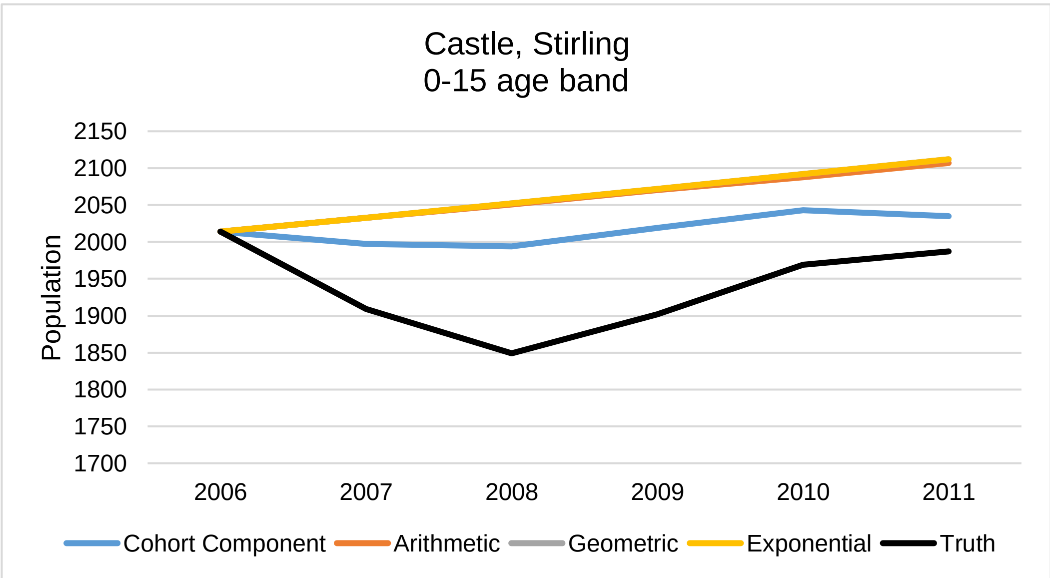
Figure 6.2 shows how the average “error” for the total population changes over the course of the projection. It can be seen from this graph that the Cohort Component method consistently had the lowest level of “error” across all years, while the other, alternative methods perform similarly to one another throughout the projection period. Despite all methods having a similar level of “error” in the first year of the projection in 2007, as the projection progresses, the Cohort Component method and the other simpler methods diverge. While the level of “error” increases for all methods as the projections continue into the future, the Cohort Component method AP“E” increases at a slower rate than the other methods. This difference in the increase in “error” over time, can be seen more clearly when comparing the “error” for each method at the beginning and the end of the projection. In the first year of the projection (2007), there is only a 0.11% difference in “error” between the Cohort Component method and the simpler methods, by 2011, the final year of the

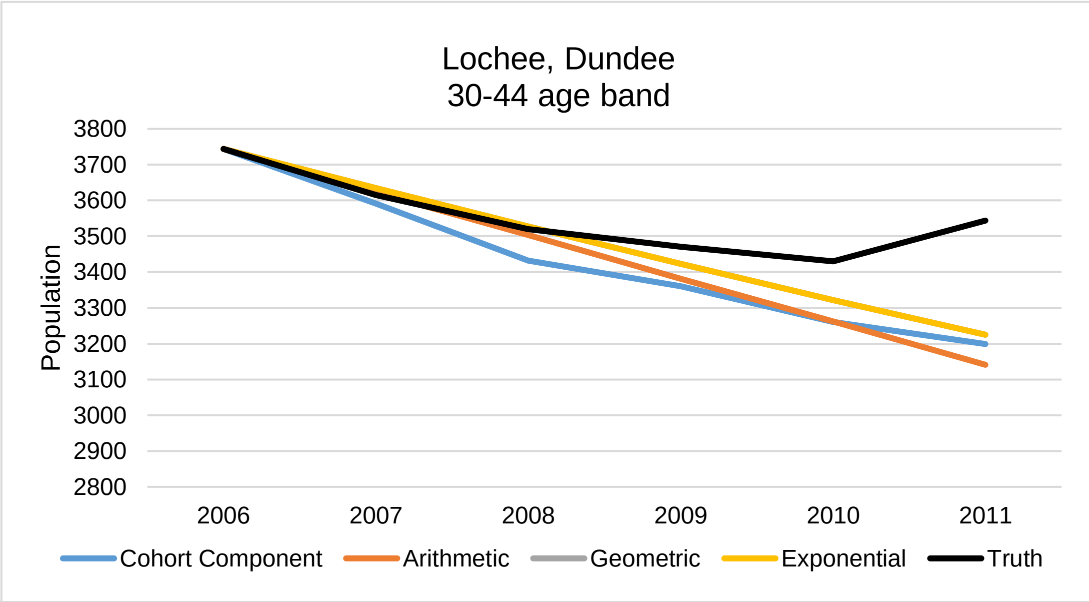
projection, this difference had increased to 1.27% between the Cohort Component method and the Arithmetic method, and a 1.35% difference between the Cohort Component method and the Geometric and Exponential methods. Overall, throughout the projection period, the AP“E” for the Cohort Component method increases by 3.04% between 2007 and 2011, while the AP“E” increased by 4.20% for the Arithmetic method and 4.27% for the Exponential and Geometric methods over the same period. This analysis shows that while the “accuracy” of projections deteriorates over time, it does not decrease by the same margin across all methods. These findings may suggest that some methods may be more appropriate for producing long term projections. This issue of length of projection will be examined further throughout this chapter.

6.3.2: Projection Examples

In order to compare the performance of these different methods over time, a selection of projections for a range of areas and age groups have been selected to demonstrate the performance of each method in different contexts.

Figure 6.3: Projections for Sample Areas





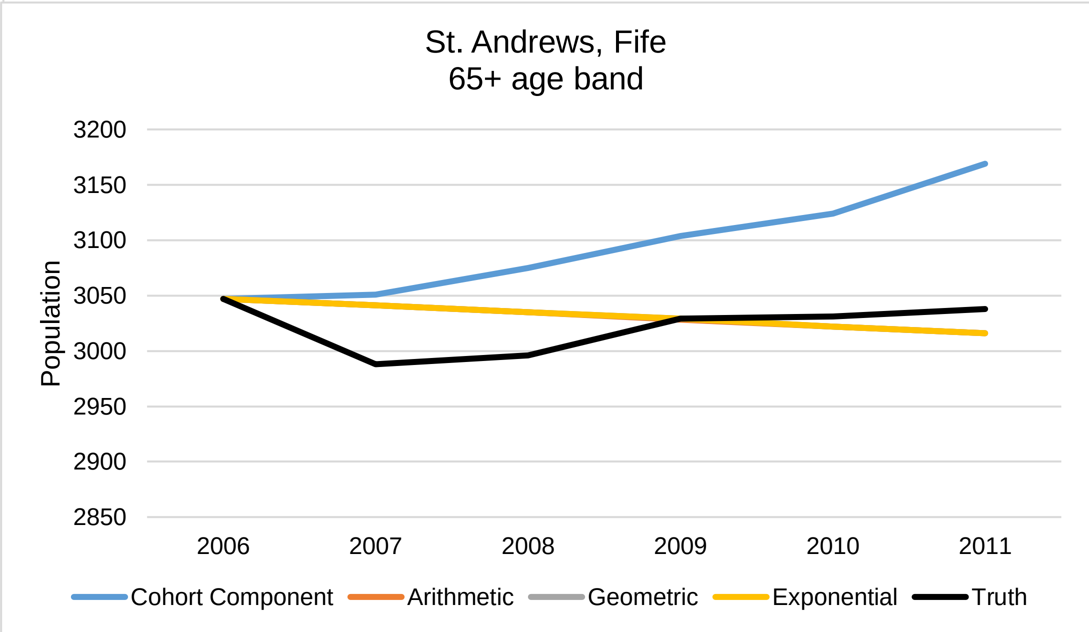


Figure 6.3 shows the projected population over time produced by each method, as well as the change in population recorded in the census and adjusted population estimates, referred to as the truth. These examples not only demonstrate how each method performs differently between areas, but the inclusion of the true population as a comparison, also highlights how changes in the population can be volatile, with large increases or decreases that may be missed by projections which continue past trends.

Firstly, looking at the Castle area, it can be seen that across all methods, there is a large disparity between the projections and the truth, particularly in the middle of the projection, in the years 2008 and 2009. Despite these discrepancies, the Cohort Component method was consistently the closest to the true population, predominantly in the final years of the projection where the difference between the Cohort Component projection and the true population was 48 people, in a population of 1,987, this is compared to a difference of 120 individuals for the Arithmetic method and 125 for the Exponential and Geometric Methods. In addition to consistently projecting population figures close to the true population, in the Castle area, the Cohort Component method was also the only approach which mirrored the increases and decreases in the true population. As the simpler methods included in this study are extrapolation methods, the population figures form a straight linear trend, even in areas where the population may be turbulent, whereas it can be seen that the Cohort Component method was better at accounting for both increases and decreases in the population.

Although the Cohort Component method produced the projection which most closely resembled the observed population change between 2007 and 2011, in the Castle area: when looking at both the Lochee and St. Andrews examples the simpler methods appear to be closer to the observed changes. In the Lochee area, projections for all methods produced similar population counts, particularly in the final year and all methods failed to account for the population increase observed in 2010. Overall in this area, the Exponential and Geometric methods most closely resembled the true population change over the projection period. This is also true in the St. Andrews example, where all the simpler mathematical methods were consistently closer to the observed population throughout the projection period. While in the early years of the projection (2007-2008) there is a large difference between all the projected population counts and the true population, as the projection progresses, the slow growth projected using the simpler methods begins to converge with the levelling off of the population which was observed. This stabilisation of the 65+ population in St. Andrews was missed by the Cohort Component method, with the projection produced using this technique indicating that the population would increase as the projection continued.

Overall, these examples of three population groups from different areas and age groups not only suggest that different methods may be more appropriate based upon the area but also that different methods may be more “accurate” based upon the year of the projection. In order to examine the performance of each of the projection methods more fully and explore the influence that factors such as projection length, age and area characteristics have on “accuracy”, multilevel models were used to explore the data.

6.3.3: Multilevel Models

While the descriptive statistics above suggest that the degree of “accuracy” found for each of the projection methods being evaluated is dependent upon area characteristics, age and year of projection, further analysis must be conducted to explore how influential each of these factors is in impacting upon the “accuracy” of population projections. In this section, multilevel models will be used to explore the influence each of these factors have upon projection “error”, and examine to what extent these models could help inform users of these statistics regarding which method may be more appropriate for producing small area population projections in their area.

Table 6.4: Null Model Random Effects

	Variance	Standard Deviation
Data zones (Intercept)	0.09015	0.3002
Residual	0.74128	0.8610

Table 6.4 shows the random effects produced by the null model which aimed to examine how much of the variance in "error" could be explained by differences between SCAP areas. As in the previous chapter, the models in this analysis use the log transform of the AP"E" for each SCAP area, therefore, to fully assess how much of the variance can be explained by area effects, a reverse logarithmic transformation was conducted for the variance values presented in Table 6.4. Similar results to those from the previous chapter were found, with around a third of the variance attributed to SCAP areas, with 34% of the variation in error attributed to area effects, and 66% of the variation due to other influences. Again, these other influences could be variables such as age or method type and in the case of this analysis, year of projection. To explore the influence of these factors in more detail, they will gradually be added to the model.

Table 6.5: Method Model

	Coefficient	Standard Error	P Value
Intercept	**0.828**	**0.02**	**<0.01**
Reference (Cohort Component)			
Arithmetic Method	0.190	0.014	<0.01
Exponential Method	0.196	0.014	<0.01
Geometric Method	0.196	0.014	<0.01
Random Effects	**Variance**	**Standard Deviation**	
Data zones (Intercept)	0.09022	0.3004	
Residual	0.73422	0.8569	

Table 6.5 shows the impact of method on projection "accuracy". This model suggests that overall, each of the mathematical methods had a positive impact upon projection "error" compared to the Cohort Component method, suggesting that, on average, population projections using these mathematical methods would be less "accurate" than the Cohort Component method. When examining the results further, it was found that, the Arithmetic method was the best of the simpler methods with a co-efficient of 0.190, compared to 0.196 for both the Geometric and Exponential methods. However, when examining these coefficients following a reverse logarithmic transformation, it can be seen that this difference is small, with a 0.84%

higher error on average for the Arithmetic method compared to the Cohort Component method, and a 0.85% increase in error on average for the Exponential and Geometric methods compared to the Cohort Component method. When exploring the impact of method, it was found that this model explained 34% of the variance in error between areas, while 66% can be attributed to other influences. To explore the factors which effect error further, age was added to the model.

Table 6.6: Method and Age Model

	Co-Efficient	Standard Error	P-Value
Intercept	**0.955**	**0.022**	**<0.01**
Method (Reference, Cohort Component)			
Arithmetic	0.190	0.013	<0.01
Geometric	0.196	0.013	<0.01
Exponential	0.196	0.013	<0.01
Age (Reference, 0-15)			
16-29	0.169	0.015	<0.01
30-44	0.031	0.015	0.03
45-64	-0.507	0.015	<0.01
65+	-0.324	0.015	<0.01
Random Effects	**Variance**	**Standard Deviation**	
Data zones (Intercept)	0.09084	0.3014	
Residual	0.67139	0.8194	

Table 6.6 shows the impact of age on "error" while controlling for area characteristics and method. When age was added, the variance in error explained by the factors included in this model increased to 36%, while 64% of the variance remained unexplained. Results of this analysis revealed similar findings to that of the population estimates analysis, with population projections for the 16-29 age group and 30-44 age group producing less "accurate" projections compared to the 0-15 reference category, with the 16-29 age group having the highest level of "error" across all age groups. Results also show that, similarly to findings in the previous chapter, the older age groups were found to have lower levels of "error" with the lowest levels of "error" found in the 45-64 age group. When comparing these results to the regression analysis conducted for the Cohort Component method, which were presented earlier in Table 6.2, it can be seen that the relationship between "error" and age differs. When evaluating the Cohort Component method in isolation, the model suggested that only the 16-29 age group produced higher levels of projection "error" compared to the 0-15 age group. When discussing these previous results, it was suggested that this higher level of "error" for the 0-15 age group may be due to changes in the fertility rate which were not captured by past trends. The findings from this current analysis of all methods may support this, with results from this

model suggesting that both the 16-29 and 30-44 age group had higher levels of "error" compared to the 0-15 age group. This result may have occurred because the simple mathematical methods, do not project forward elements of population change but rather population change as a whole. It is this difference which could explain why the pattern of "error" between age groups may vary between methods. In order to explore the different effects which each of the variables examined have on each method further, an interaction model will be used later in this section.

Table 6.7: Method, Age and Projection Length Model

	Co-Efficient	Standard Error	P-Value
Intercept	**0.41**	**0.02**	**<0.01**
Method (Reference, Cohort Component)			
Arithmetic	0.19	0.01	<0.01
Geometric	0.20	0.01	<0.01
Exponential	0.20	0.01	<0.01
Age (Reference, 0-15)			
16-29	0.17	0.01	<0.01
30-44	0.03	0.01	0.02
45-64	-0.51	0.01	<0.01
65+	-0.32	0.01	<0.01
Year of Projection (Reference: Year 1)			
Year 2 of Projection	0.35	0.01	<0.01
Year 3 of Projection	0.60	0.01	<0.01
Year 4 of Projection	0.79	0.01	<0.01
Year 5 of Projection	0.96	0.01	<0.01
Random Effects	**Variance**	**Standard Deviation**	
Data zones (Intercept)	0.09201	0.3033	
Residual	0.55526	0.7452	

Table 6.7 shows the results of the regression model when the year of projection is added. These results suggest that as the projection period increases, the projections become less "accurate" with the model showing that the "error" is higher for each year of the projection compared to year one. The "error" also appears to steadily increase over time with the co-efficient for each year increasing as the year of projection increases. When adding length of projection to the model, the percentage of variance in error explained by this model again increased to 39%.

While all the variables explored in these models help to understand some of the factors which influence projection "error", they do not provide information regarding why differences in "error" were found in areas when using the same method, and producing projections for the same age groups and years. Although results of the

Null Model presented in Table 6.4 suggest that area characteristics have some influence on projection “accuracy”, in order to examine which demographic factors have the greatest influence on the “accuracy”, individual area characteristics must be added to the model.

Table 6.8: Full Model

	Co-Efficient	Standard Error	P-Value
Intercept	**0.45**	**0.02**	**<0.01**
Method (Reference, Cohort Component)			
Arithmetic	0.19	0.01	<0.01
Geometric	0.20	0.01	<0.01
Exponential	0.20	0.01	<0.01
Age (Reference, 0-15)			
16-29	0.10	0.01	<0.01
30-44	0.02	0.01	0.26
45-64	-0.48	0.02	<0.01
65+	-0.47	0.02	<0.01
Year of Projection (Reference: Year 1)			
Year 2 of Projection	0.35	0.01	<0.01
Year 3 of Projection	0.60	0.01	<0.01
Year 4 of Projection	0.80	0.01	<0.01
Year 5 of Projection	0.97	0.01	<0.01
Arrived within a year (International Migration) (%)	0.05	0.03	0.07
Communal Population (%)	0.03	0.00	<0.01
Non-White (%)	0.01	0.01	0.19
One Person Household (%)	0.00	0.00	0.24
Overcrowding (%)	0.02	0.01	<0.01
Population Growth (%)	0.01	0.00	<0.01
Population Size	-0.00	0.00	<0.01
Students (%)	-0.01	0.01	0.42
Unemployed (%)	-0.03	0.01	0.04
Unoccupied Housing (%)	0.02	0.02	0.30
Random Effects	**Variance**	**Standard Deviation**	
Data zones (Intercept)	0.0631	0.2512	
Residual	0.5497	0.7414	

Table 6.8 shows results from the full regression model, including area characteristics. In this final model, the variables included were found to account for 38% of the variation in error between areas. The results of this analysis mirror some of the results from the model presented in Table 6.2 which evaluated only the Cohort Component method. As with the previous model presented in Table 6.2, results from this analysis found that only a limited number of the area characteristics included in

this model had any significant impact upon “error”, with population size and the proportion of one person households both found to have a negative impact upon “error” with only population growth and the communal population being found to increase “error”. These results are largely to be expected, with this model suggesting that population projections would be more “accurate” in areas with larger populations and less “accurate” in areas with high levels of population change. The results of this analysis also support suggestions made earlier in this chapter that, in most cases, it is more difficult to pinpoint the particular area characteristics which influence the “accuracy” of population projections, despite evidence to suggest that these projections perform better in some areas compared to others, as illustrated in the examples shown in Figure 6.3.

While these results suggest that individual area characteristics may not be useful as predictors of projection “error”, by using an interaction model to study the factors which could influence “error” in greater detail, it may be possible to examine how each of these variables influence the projections produced by different methods. By using an interaction model it may be shown that particular demographic factors influence the “accuracy” of projections used by some methods to a more significant degree compared to others.

Figure 6.4: Interaction Model “Error”

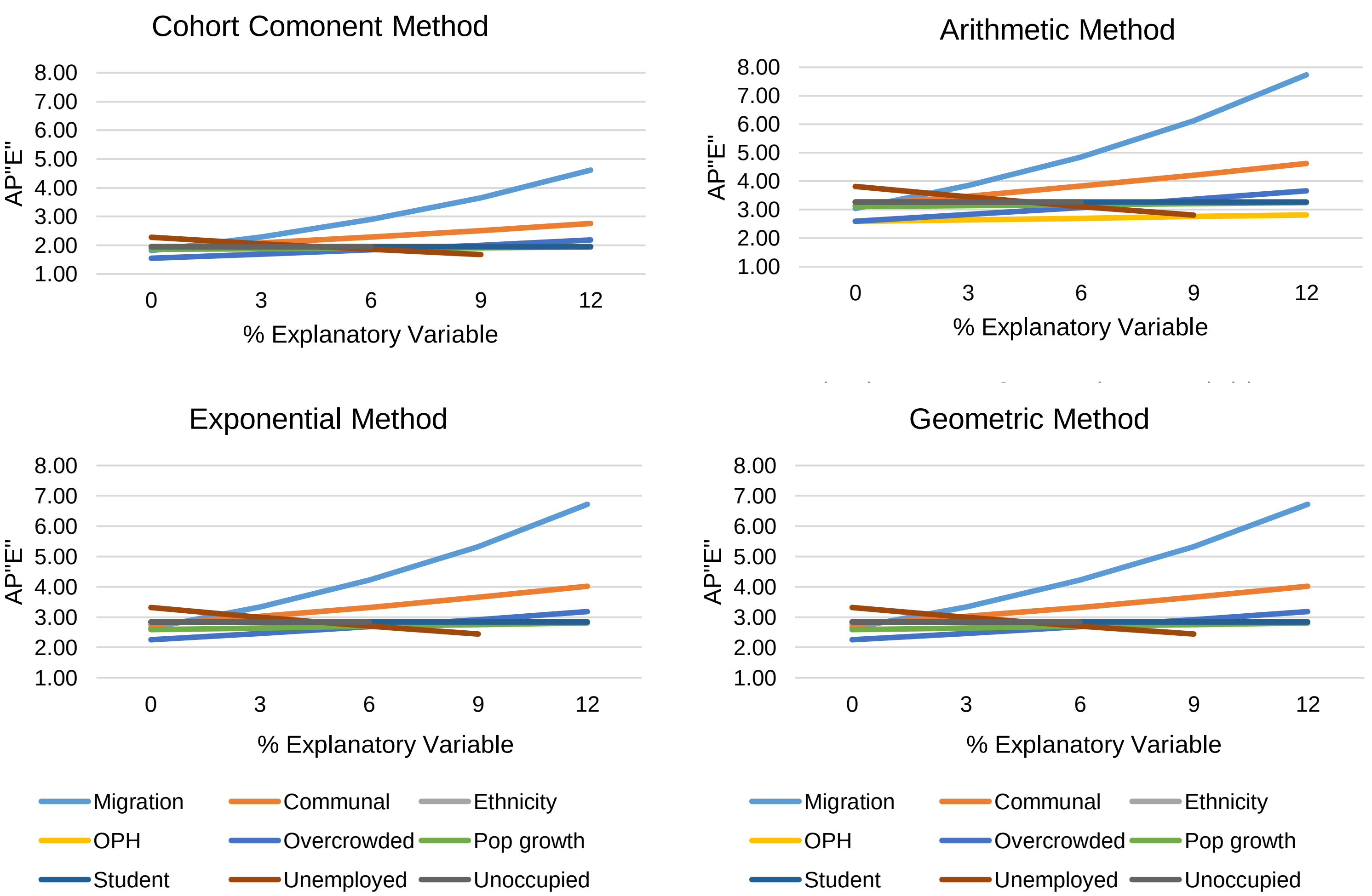


Figure 6.4 shows the results of the interaction model error which illustrates how the error changes in an average area for year three of the projection and for the 30-44 age group, using the same variables as the model error presented in Figure 6.1. The full interaction model output can be found in Appendix I. When examining the interactions between method and area characteristics using model error, there appears to be little difference in the influence of the area characteristics included in this model between methods. From Figure 6.4, it can be seen that the pattern of the changes in error is very similar across methods. For a majority of the area characteristics included in this model, there was no statistically significant difference between their influence on the Cohort Component method and the simpler methods. The exceptions to this is the proportion of one person households which was found to have a greater influence on error for projections produced using the Arithmetic method compared to the Cohort Component method, and the population growth variable which was found to have a greater influence on the accuracy of the Exponential and Geometric projections compared to the Cohort Component method.

Figure 6.5: Method and Age Interaction

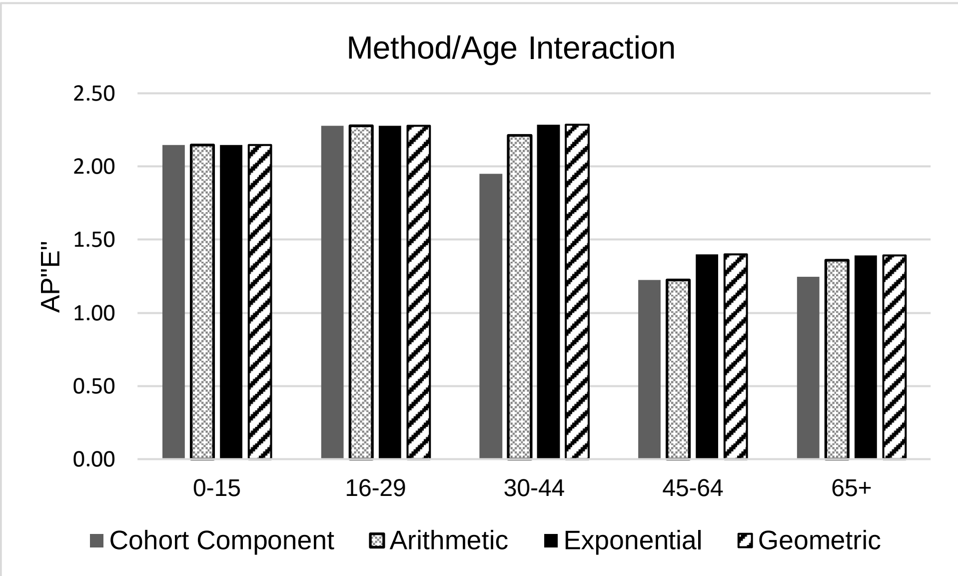


Figure 6.5 shows the interaction between method and age group. From this analysis, it can be seen that, for the younger age groups (0-15 and 16-29), there was no difference in the effect of age between methods. However, for the older age groups, there was more variation. For the 30-44 age group, it was found that each of the simpler methods produced a higher level of error compared to the Cohort Component method, with the Exponential and Geometric methods producing the highest “error”. When examining the differences in error for the 45-64 age group, it can be seen from Figure 6.5 that there was no significant difference found between the Arithmetic method and the Cohort Component method while for the Exponential and Geometric methods, there was a higher level of “error” associated with this age group. Finally, for the 65+ age group, the “error” was lowest for the Cohort Component method, while the simpler methods produced projections with a higher

level of "error" for this age group, with little difference in the performance of these simpler methods. From these results, it appears that there is some evidence to suggest that there is an association between method and age, with the "accuracy" of small area population projections for each age group differing based upon the projection method used, particularly for older age groups.

Figure 6.6: Method and Year Interaction

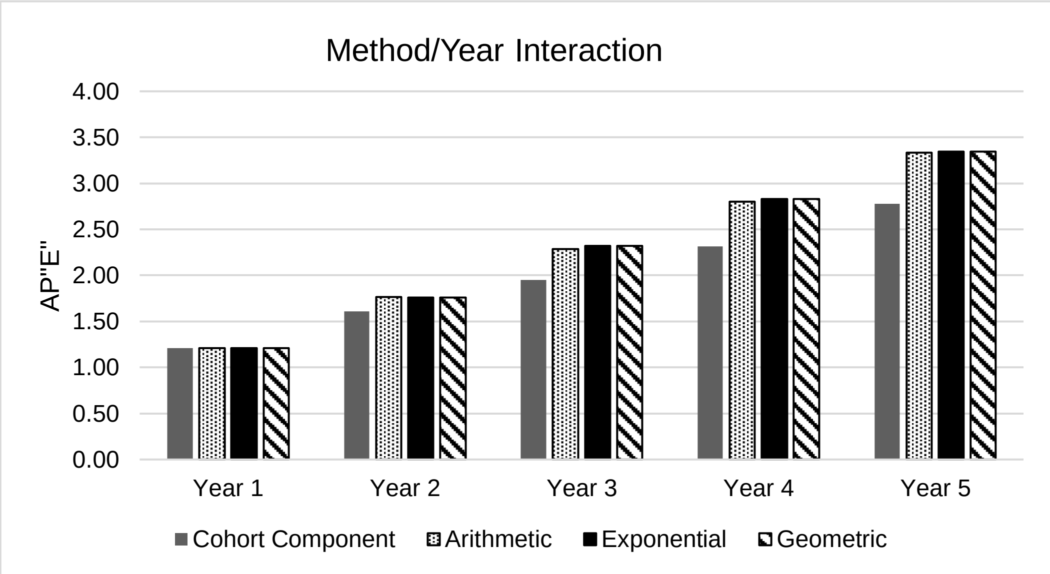


Figure 6.6 shows the interaction between method and year of projection. From this visualisation, it can be seen that for each method, "error" increases with the length of the projection period. Interestingly, there is also a clear difference in the rate of the increase in "error" between the Cohort Component method and each of the simpler methods. In the early years of the projection, there is little difference between methods, however, as the projection continues, a greater divergence emerges between the Cohort Component method and the simpler methods; with the "error" present in projections produced using the simpler methods increasing more rapidly than the Cohort Component method. Overall, it was found that between Year 1 and Year 5, the error increased by 1.57% for the Cohort Component method, while the error in projections produced using the Arithmetic method and the Exponential and Geometric methods increased by 2.12% and 2.13% respectively. This issue of how the "accuracy" of these population projections produced by different methods changes over the projection period will be explored in greater detail in Section 6.4 of this chapter.

6.3.4: Case Study Areas

These findings suggest that, as well as individual area characteristics having only a limited impact on projection "error" overall, there also appears to be little variance in the impact of these area characteristics between methods. In order to explore these interactions further and to more clearly demonstrate any difference between areas or methods that may exist, the output from this model will be used to produce predicted error for two case study areas. In this section of the research, the predicted "error" for two contrasting areas will be compared, to examine whether the variables which were included in this model can help to account for differences in projection "accuracy" between areas.

<u>Case Study Area One: Stromness Parish</u>

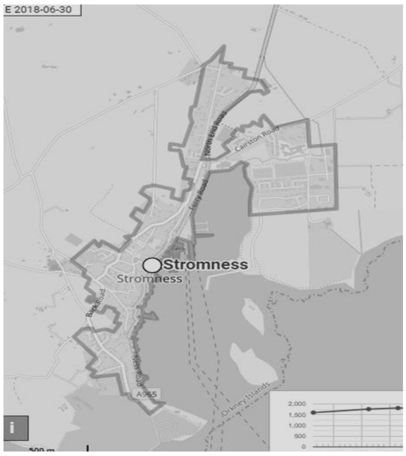


Figure 6.7: Stromness, Orkney (Source: Citypopulation.de)

The first area which will be studied in this section is the housing market area of Stromness Parish on the Orkney Islands. This is the SCAP area with the smallest population of all areas in this study, with a 2011 census population of 2,055. This is the second largest town in Orkney, situated on the West Mainland (Orkney Education, Leisure and Housing Committee, 2019). Stromness Parish has a fairly even age profile, with slightly lower populations of 16-29 year olds and modestly higher levels of 30-44 and 45-64 year olds. Census data shows that this area has only a small student population and low levels of unemployment. Overall, the most significant feature of this area, along with its small population, is its high level of population growth, in particular the increase in the 16-29 and 65+ age groups where the population increased by around 20% between 2001 and 2011, while the 30-44 age group fell by 14%.

Table 6.9: Predicted "Error" Stromness Parish

Cohort Component Method					
	Year One	**Year Two**	**Year Three**	**Year Four**	**Year Five**
0-15	1.53 *(5)*	2.03 *(7)*	2.47 *(8)*	2.93 *(10)*	3.51 *(12)*
16-29	1.78 *(5)*	2.36 *(7)*	2.86 *(8)*	3.39 *(11)*	4.07 *(12)*
30-44	1.45 *(6)*	1.93 *(8)*	2.34 *(9)*	2.78 *(11)*	3.34 *(13)*
45-64	0.90 *(5)*	1.19 *(7)*	1.45 *(9)*	1.72 *(10)*	2.06 *(12)*
65+	1.15 *(5)*	1.53 *(6)*	1.86 *(8)*	2.20 *(10)*	2.64 *(12)*
Total[11]	**1.29** ***(26)***	**1.71** ***(35)***	**2.07** ***(42)***	**2.47** ***(51)***	**2.95** ***(61)***
Arithmetic Method					
0-15	2.06 *(6)*	2.99 *(10)*	3.87 *(13)*	4.75 *(16)*	5.64 *(19)*
16-29	2.38 *(7)*	3.55 *(10)*	4.60 *(13)*	5.63 *(18)*	6.70 *(20)*
30-44	1.95 *(8)*	3.21 *(13)*	4.17 *(16)*	5.11 *(19)*	6.07 *(23)*
45-64	1.21 *(7)*	1.85 *(11)*	2.40 *(14)*	2.94 *(18)*	3.49 *(21)*
65+	1.55 *(6)*	2.45 *(10)*	3.18 *(13)*	3.90 *(17)*	4.63 *(21)*
Total	**1.73** ***(34)***	**2.67** ***(54)***	**3.46** ***(70)***	**4.25** ***(87)***	**5.03** ***(103)***
Exponential/Geometric Method					
0-15	1.54 *(5)*	2.23 *(7)*	2.94 *(10)*	3.59 *(12)*	4.25 *(14)*
16-29	1.91 *(5)*	2.77 *(8)*	3.65 *(10)*	4.45 *(14)*	5.26 *(16)*
30-44	1.78 *(7)*	2.59 *(10)*	3.41 *(13)*	4.17 *(16)*	4.93 *(19)*
45-64	1.07 *(6)*	1.55 *(9)*	2.05 *(12)*	2.50 *(15)*	2.95 *(18)*
65+	1.38 *(5)*	2.00 *(8)*	2.63 *(11)*	3.22 *(14)*	3.79 *(17)*
Total	**1.47** ***(29)***	**2.13** ***(43)***	**2.81** ***(57)***	**3.43** ***(71)***	**4.05** ***(83)***

[11] Total = sum of error as number of individuals in each age group as a percentage of total population

Table 6.9 shows the predicted projection “error” by year, age and method for the Stromness SCAP area in Orkney, with the equivalent number of individuals in parentheses. From this predicted “error”, it can be seen that the Cohort Component method produced the lowest level of “error” across all age groups and years, with a total “error” of 2.95%, in the final year of the projection, equivalent to an error of 61 individuals in a population of 2,055, while the Arithmetic method had a total error of 5.03% (103 people) and the Exponential and Geometric methods an “error” of 4.05% (83 people) for the same year. The Arithmetic method produced the least “accurate” projections for this area, with the highest levels of “error” across all years and ages. When looking at the differences in “error” by age, the results are largely in line with the findings from the regression analysis presented in Table 6.8, with higher levels of “error” found for the 16-29 age group, and lower levels of “error” found for the older adult age groups (45-64 and 65+). However, when converting these percentage “errors” to the equivalent number of individuals, it shows that in real terms, the differences in “error” between age groups is small, with the error ranging between one and two individuals in a majority of cases. An example of this, is in the population projection produced by the Cohort Component method for year three of the projection, where the percentage “error” equates to eight people for the 0-15, 16-29 and 65+ age groups, and nine people for the 30-44 and 45-64 age groups. This small difference in error between age groups was found for all methods and across all years of the projection, with the largest difference found in year five for the projections produced using the Arithmetic method, where the “error” varied between nineteen and twenty-three individuals between age groups. This even performance of each projection method may be due to the relatively equal distribution of the population between age groups. While some areas may have a skewed age profile, attracting populations belonging to one particular age demographic, the area of Stromness had a more mixed age profile, with no one age group having a significantly higher population than any others.

<u>Case Study Area Two: Tillydrone / Seaton / Old Aberdeen</u>

The second area of study in this section is the Tillydrone / Seaton / Old Aberdeen ward in Aberdeen City. In contrast to the previous area, this a more densely populated urban area with the 2011 census recording a population of 17,988. This area can be defined as a largely student area, with a third of the population falling into the 16-29 age group and a third of the population students. While the previous example had relatively low levels of each of the variables included in this model, such as individuals living in communal populations, numbers of students and only a small ethnic minority population; this area contrasts greatly, with far more significant proportions of all variables examined in this research. This contrast of areas will help to assess the extent to which area

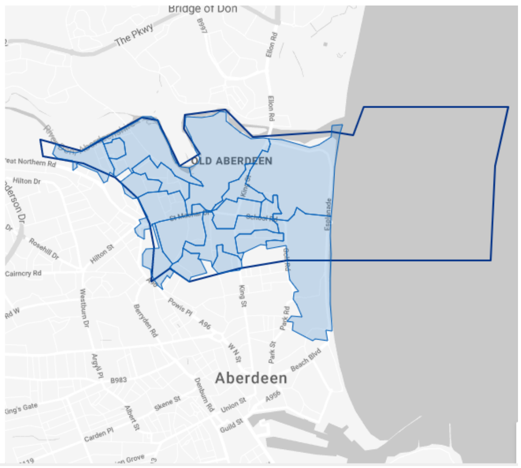


Figure 6.8: Tillydrone/Seaton/Old Aberdeen, Aberdeen City (boundaries from Scot.Stat, 2019)

characteristics impact upon the “accuracy” of each projection method.

Table 6.10: Predicted “Error” Tillydrone/Seaton/Old Aberdeen

Cohort Component Method					
	Year One	**Year Two**	**Year Three**	**Year Four**	**Year Five**
0-15	3.79 *(73)*	5.05 *(94)*	6.11 *(115)*	7.21 *(142)*	8.64 *(74)*
16-29	12.75 *(779)*	16.75 *(1055)*	19.60 *(1364)*	22.77 *(1675)*	26.20 *(2134)*
30-44	3.78 *(102)*	5.00 *(138)*	5.98 *(179)*	7.05 *(221)*	8.40 *(274)*
45-64	2.03 *(53)*	2.67 *(74)*	3.23 *(91)*	3.82 *(110)*	4.57 *(134)*
65+	2.24 *(40)*	2.98 *(52)*	3.62 *(61)*	4.31 *(71)*	5.18 *(84)*
Total	**6.91 *(1047)***	**9.17 *(1412)***	**11.08 *(1810)***	**13.07 *(2218)***	**15.57 *(2801)***
Arithmetic Method					
0-15	5.15 *(99)*	7.52 *(140)*	9.74 *(183)*	11.89 *(243)*	14.09 *(184)*
16-29	17.34 *(1059)*	25.57 *(1610)*	32.00 *(2228)*	38.42 *(2826)*	43.75 *(3563)*
30-44	5.14 *(139)*	8.44 *(233)*	10.82 *(323)*	13.16 *(412)*	15.52 *(507)*
45-64	2.76 *(72)*	4.20 *(115)*	5.43 *(153)*	6.63 *(191)*	7.85 *(231)*
65+	3.05 *(54)*	4.85 *(84)*	6.31 *(106)*	7.75 *(128)*	9.22 *(149)*
Total	**9.40 *(1424)***	**14.18 *(2182)***	**18.33 *(2993)***	**22.33 *(3790)***	**26.32 *(4735)***
Exponential/Geometric Method					
0-15	3.99 *(77)*	5.81 *(108)*	7.65 *(144)*	9.30 *(183)*	10.96 *(221)*
16-29	14.94 *(912)*	21.46 *(1351)*	27.30 *(1901)*	32.64 *(2401)*	36.96 *(3010)*
30-44	4.85 *(131)*	7.01 *(193)*	9.13 *(273)*	11.07 *(346)*	12.97 *(424)*
45-64	2.38 *(62)*	3.43 *(94)*	4.50 *(127)*	5.48 *(158)*	6.46 *(190)*
65+	2.69 *(48)*	3.91 *(68)*	5.17 *(87)*	6.32 *(104)*	7.48 *(121)*
Total	**8.12 *(1231)***	**11.79 *(1815)***	**15.50 *(2531)***	**18.80 *(3192)***	**22.05 *(3966)***

Table 6.10 shows the predicted “error” for the Tillydrone/Seaton/Old Aberdeen ward in Aberdeen City. The most striking result from this analysis is the significantly higher levels of “error” found for the 16-29 age group, with the “error” peaking in year five of the projection and ranging from an “error” of 26.20% for the Cohort Component method to 43.75% for the Arithmetic method. This would suggest that age may have a significant impact upon “error” when there are larger populations of particular age groups concentrated within an area. In this part of Aberdeen City, the 16-29 age group had the largest population, with more than double the population of this age group compared to others. As discussed in the previous chapter, with reference to population estimates, it may be expected that this higher population of 16-29 year olds would reduce the “error” for this area as previous findings from the regression analysis suggest that population size is inversely correlated with “error”, with “error” decreasing as the population size increases; however, in this particular area the 16-29 age group also experienced the highest proportion of population change over the projection period, with the census showing a population increase of almost 50% between 2001 and 2011. Results from the regression model show that population growth had a greater influence on “error” than population size, suggesting that in this

area, the effect of population change, along with the increase in “error” already associated with the 16-29 age group, is responsible for the elevated levels of “error” found for this age group. Overall, as with the first case study area, results of this model “error” show that the most “accurate” projection method was the Cohort Component method, while the Arithmetic method produced the least “accurate” projections across all age groups and for each year of the projection.

When comparing error for these two areas, it can be seen from these results, that across all methods, ages and years, that the “error” differs between areas, with higher levels of error found in the Tillydrone/Seaton/Old Aberdeen area compared with the Stromness Parish area of Orkney. This suggests that, as with the population estimates evaluated in the previous chapter, area characteristics and demographics do have an impact upon the “accuracy” of population projections, with projections more “accurate” in some areas compared to others.

As well as area characteristics, the effects of age and year of projections were also found to influence error. There was little difference in “error” found between age groups in real terms for the Stromness Parish area, however, when comparing the percentage “error” for both areas, the differences were as expected, with the highest levels of “error” for the 16-29 age group and lower levels of “error” found for the older adult age groups. When looking at how “accuracy” changes over time, these results would also be expected, with “error” increasing as the projection period increased. When comparing methods, it can also be seen from this analysis, that the “error” produced by the simpler, mathematical methods increases more quickly in comparison to the Cohort Component method; with the “error” for the total population for the Stromness Parish area increasing by 1.66% for the Cohort Component method and increasing by 3.30% and 2.32% for the Arithmetic method and the Exponential/Geometric methods respectively, while the total population “error” for the Aberdeen City area increased by 8.66% for the Cohort Component method, and 16.92% and 13.96% for the Arithmetic and Exponential/Geometric methods respectively. These findings suggest that over a longer projection period, the Cohort Component method would be a more reliable approach compared to the simple methods.

Overall, the predicted “error” for both of these case study areas show that the Cohort Component method was the best performing method across all age groups and for each year of the projection. While this may be expected, with the regression models showing that this approach was, on average, the most “accurate”, however, when comparing the two case study areas, there are some differences in the performances of the simpler methods, with the predicted “error” produced by these methods much closer to that produced by the Cohort Component method for Stromness Parish compared to the Tillydrone/Seaton/Old Aberdeen area where the Cohort Component method outperformed the simpler methods by a more substantial margin. This may suggest that while the regression analysis suggested that the effects of area characteristics on “error” may be limited, when the results of the regression models are applied to particular areas, even the limited impact of demographic factors may result in meaningful differences in projection “accuracy” between areas.

Results from these case study areas, as well as earlier models may suggest that area characteristics, age and length of projections all have an influence on projection "accuracy" for all methods, with some areas and age groups producing more "accurate" projections compared to others. When comparing methods, this analysis suggests that the Cohort Component method is the most reliable projection method, maintaining a more consistent level of "accuracy" throughout the projection period. However, there is some evidence to suggest that, at least in some areas, the simpler methods can produce population projections to a similar level of accuracy to the Cohort Component method. The issue of "accuracy" weighed against the cost and ease of production of these simpler methods will be discussed in more detail in a later chapter.

6.4: PROJECTIONS OVER THE PROJECTION PERIOD

As the purpose of a population projection is to give an indication of what the population may be in the future, it is important to understand how the "accuracy" of projections change over time, and how long a projection period can stretch while still being fit for purpose. While results from the previous sections of this chapter have shown evidence which suggests that "error" present in population projections increases as the projection period lengthens, this section will explore the issue in greater detail. While there may be demand from users to have long term projections for small areas, Smith et al (2013:364) explain that "*Projections which extend very far into the future simply cannot provide highly accurate forecasts*". This section will therefore focus on the reliability of small area projections over time in order to provide users with some insight into how far into the future a projection can span and remain reliable and useful to their purposes.

6.4.1: Projection Shelf Life

One way of measuring the usefulness of population projections over time, is by examining their shelf life. This concept of 'shelf life' for population projections was developed by Simpson et al (2018) to give an indication of the uncertainty present in population projections for users and is defined as, the length of horizon which can be reached where the projected population remains within 10% of the true population in 80% of cases. This definition will be used in this research to compare the "accuracy" of the total population projections produced by each method over the projection period.

Figure 6.9: "Shelf-Life" of Projections

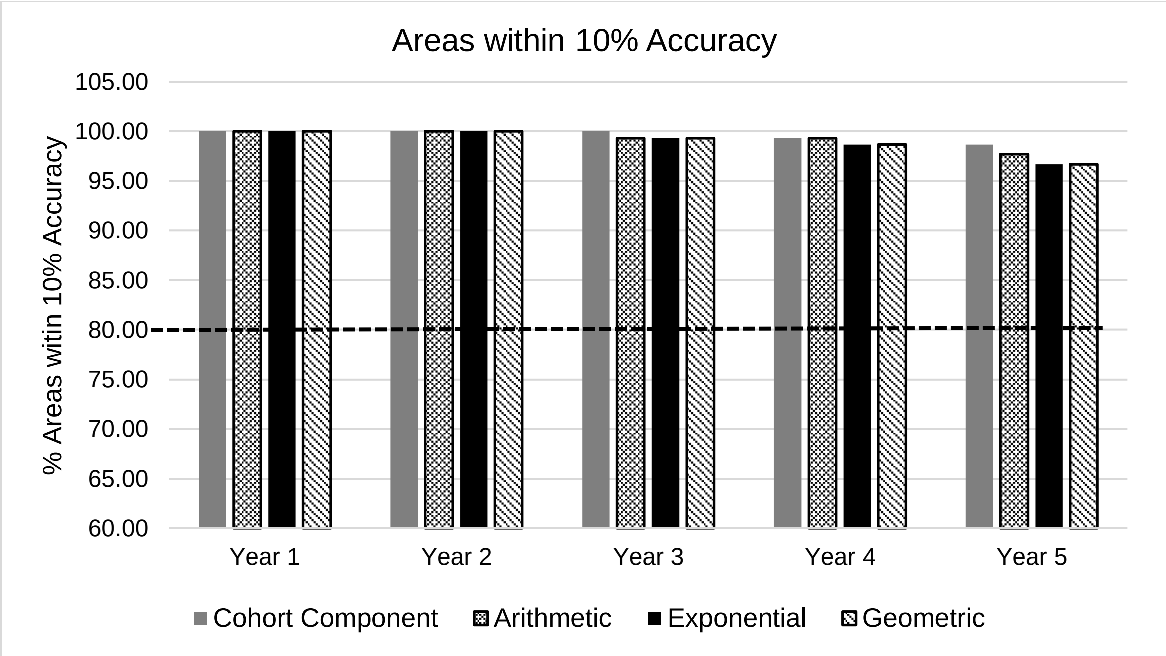


Figure 6.9 shows the proportion of areas where the population projections fall within 10% of the true population. It can be seen from this chart that, across all years, every method produced projections which were within 10% of the true population over 80% of the time. For the first two years, 100% of the projections had less than 10% error, with the Cohort Component method maintaining this level of accuracy in Year 3 of the projection. It is in Year Five that a larger divergence between the methods emerges, with the proportion of areas falling within this "accuracy" for each method separated by 1%, with the Cohort Component method having 98.7% falling within 10% "accuracy", the Arithmetic method 97.7% and the Exponential and Geometric methods 96.7%. The most important finding from this analysis, is the finding that over a five-year projection, all methods included in this study fell comfortably within the 10% of the truth 80% of the time definition of 'shelf life' defined by Simpson et al (2018). This suggests that all of these methods can be considered to be reliable and useful over a short-term five-year projection for the total population.

This initial analysis deals with total population projections, emulating the work carried out by Simpson et al (2018). However, as previously discussed, age specific population statistics are of great importance to users, particularly when targeting resources at specific demographic groups. For this reason, the shelf-life analysis was repeated using age-specific population projections, with the population broken down into age groups as discussed in the previous analysis in this chapter.

Figure 6.10: Age Specific 'Shelf Life'

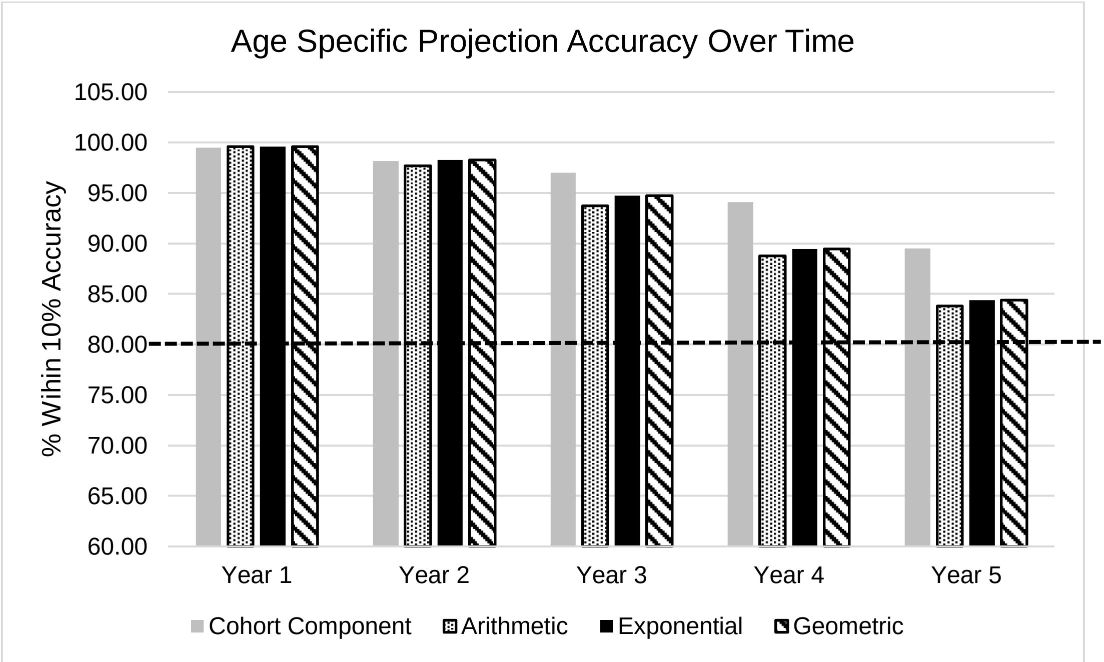


Figure 6.10 shows the proportion of areas whose population projections fell within 10% accuracy across a five-year projection period. It can be seen that, as with the total population projections, all methods included in this analysis met the definition of shelf life defined by Simpson et al (2018), with more that 80% of areas being with in a 10% accuracy across all years of the projections. As with the previous results presented in Figure 6.9, by Year 3 of the projection, the Cohort Component method and the simpler methods begin to diverge, with the accuracy of the Cohort Component method decreasing more slowly over time compared to the simpler methods. While in Year 1 of the projections, all methods had over 99% of areas within 10% accuracy, by Year 5, this had dropped to 89.5% for the Cohort Component method and 84% for each of the simpler methods.

Overall, these findings suggest that, when evaluating the "accuracy" of population projections, all of the methods studied in this project perform to a similar degree of "accuracy" across the projection period, particularly for the total population. When considering the concept of 'shelf life', results from this analysis suggests that, all methods can be considered reliable and useful for a projection spanning at least five years, for both total and age-specific projections. For users who desire projections with a higher degree of "accuracy", results presented in Figure 6.9 and 6.10 suggest that the Cohort Component method would be the most reliable over a five-year projection. Overall, using this analysis to track how the "accuracy" of population projections change over time, the results of this analysis support the findings discussed previously in this chapter. In both Figure 6.9 and 6.10 it can be seen that not only does the "accuracy" of population projections fall over time, but that the "accuracy" of projections produced using simpler methods declines more quickly compared to the Cohort Component method. This suggests that over longer projection horizons, the Cohort Component method may produce more "accurate" and reliable projections compared to the simple approaches.

6.4.2: Direction of Error

As well as understanding how “error” changes over time in absolute terms, it is also important to understand the type of “error” present in population projections. By examining the direction of “error” present in projections, and how this may change throughout the projection period, it could help to explain why “error” may occur and aid users’ interpretation of projections. As in the analysis of the population estimates in the previous chapter, the “error” for each year and method were coded as Accurate, Over-Estimated or Under-Estimated, with ‘accurate’ referring to a projection within 5% of the true population.

Figure 6.11: Change in Error Type by Method

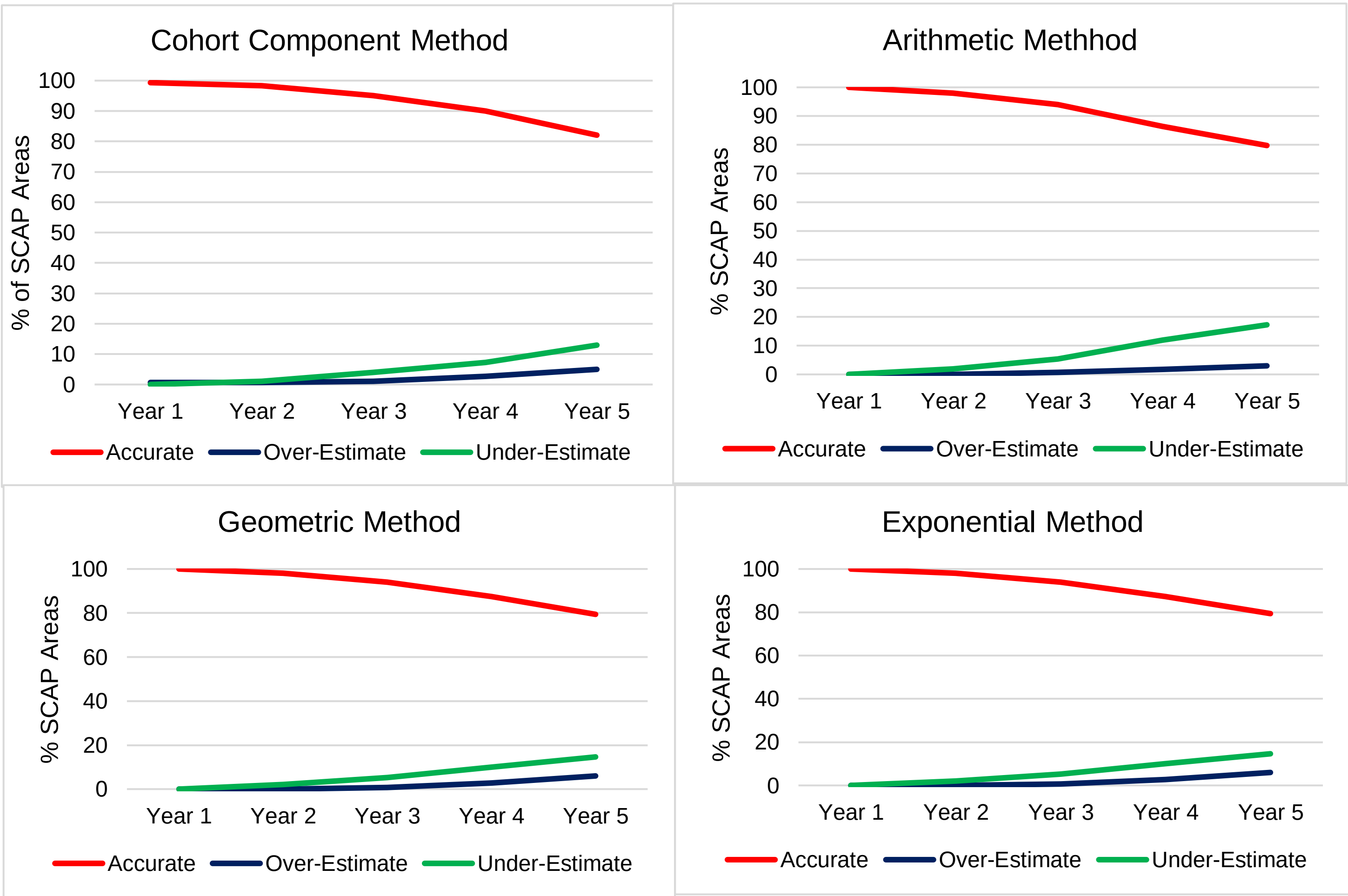


Figure 6.11 shows how the type of error observed changes over time for each method for the total population. It was found that for all the alternative methods, all of the areas in 2007 were accurately projected, meaning that the error was 5% or less. When examining the Cohort Component method 99.33% of areas were accurately estimated, with only two areas, (St Andrews and Meadows/Morningside), over-

estimated. Over the course of the projection period, a similar pattern can be seen for all methods, with the proportion of under-estimated areas increasing more quickly than over-estimated areas as the projection continues and the proportion of "accurate" areas decreases. This is most evident for the Arithmetic method where, by the final year of the projection, 17.3% of areas were under-estimated compared to 3% of areas over-estimated.

Although this is a limited sample of projection methods, these findings suggest that when population projection methods do produce "error", they are more likely to under-estimate than over-estimate the true population. This trend towards under-estimation may suggest that these projections fail to capture increases in the population. When examining the individual areas which produced the highest under-estimates in this project, it was found that the Tillydrone/Seaton/Old Aberdeen had the greatest under-estimate for the Cohort Component and Arithmetic methods, while the East Garioch area of Aberdeenshire had the greatest under-estimate for the Exponential and Geometric methods. One feature which both of these areas have in common is that their populations grew rapidly between 2001 and 2011, according to census data.

Looking at the Tillydrone/Seaton/Old Aberdeen area, which was previously featured in this project as a case study area, analysis of census data shows that the population increased by 24% over a ten-year period. This growth was largely driven by an increase in young adults, with the 16-29 age group growing by 48% and the 30-44 age group growing by 27% over the same period. The fact that this area saw the biggest increase in the young adult age groups may be significant in explaining the higher levels of "error" and under-estimation experienced by this area, as it is these age groups which previous analysis has shown to be associated with higher levels of "error". When looking at census data for the East Garioch area of Aberdeenshire, it can be seen that this area also experienced a substantial increase in the population, with the population growing by 57.3% from 7,618 in 2001 to 11,985 in 2011. This growth occurred across all age groups from a 82.4% increase in 0-15 year olds to the smallest increase of 35.1% for 16-29 year olds.

Overall, taken together, these finding suggest that one short coming of all of the methods in this study is a failure to capture increases in the population in rapidly growing areas. While a vast majority of the projections produced by each method had an "error" of less than 5%, in cases where there was "error", results from this research suggests that it is most likely to occur in an area experiencing high levels of population growth which were not accounted for when continuing past trends.

6.5 CONCLUSION

In this chapter, population projections produced using the Cohort Component method were compared to alternative projections produced using simpler mathematical methods. Findings from this support the use of the Cohort Component method for producing Scotland's small area population projections, with this method producing highly “accurate” projections when evaluated in its own right, and proving to outperform simpler methods.

Results from the statistical analysis conducted in this chapter suggests that the Cohort Component method is the most effective and reliable method when producing small area population projections in Scotland across the projection period. However, there was also some evidence to suggest that simple methods may also be appropriate in some cases, with shelf life analysis suggesting they can produce reliable projections over a short period, with the error only modestly higher compared to the Cohort Component method. This may mean that while the Cohort Component method may be the most suitable and reliable for producing official population projections, there may be a place for simpler methods to be used by local analysts where it is not possible to apply the Cohort Component method due to a lack of resources, data or skill. The results from this research may provide local analysts with the information to make an informed decision whether using a simple method would provide them with enough demographic detail and to a high enough standard to meet their requirements.

These views of local users and their understanding of how projections are used, are an important factor in helping to evaluate population statistics. While this chapter and the previous chapter have evaluated a range of projection and estimation methods from a purely statistical perspective, in order to fully understand how precise these small area population statistics must be, to be a valuable resource and to what extent each method is fit for purpose, the views and experiences of users of these population statistics must be taken into account and will be explored in the next chapter.

Chapter 7: Making Plans: Judging Accuracy and Accommodating Error

7.1: INTRODUCTION

While the previous analysis in this project has focused upon quantifying the accuracy of small area population estimates and projections, this chapter aims to look beyond quantitative methods to evaluate the usefulness of population statistics to users, and in particular, the way in which the error examined in previous chapters is interpreted by users, in practice. Whilst the previous quantitative analysis is important for measuring error in population statistics, it fails to take into account the practical consequences of error for planners. Population estimates and projections do not exist in isolation, but rather they are produced as tools for planners and policy makers to engage with and in turn affect demographic change itself. By understanding how users interact with the population statistics currently available in Scotland, this chapter provides a greater insight into why the study of accuracy is important, as well as the complex, often area-specific issues which can impact on the usefulness of population statistics beyond numerical error. As Burch (2017:7) writes; "*All models are approximations. The question is whether the approximation is good enough for the purpose at hand. All models have a limited number of variables; none can mirror the numberless qualities of the real world. And finally, any model is to be evaluated with reference to the purpose for which it has been designed or constructed".* Here, Burch (2017) summarises the aims of this chapter, to expand the research beyond an empirical evaluation of the performance of estimation and projection models.

This chapter aims to explore the way in which local users interpret and employ population statistics from a number of perspectives, with particular attention given to local users' expectations of accuracy and how the potential for error is incorporated into planning decisions. In order to explore these issues, this chapter will be split into six sections. The first of these sections seeks to explore who uses these estimates and projections and how they are used; aiming to provide some context and insight into how widely these population figures are used. Following this background information, the second section examines why users require small area population statistics to a high degree of accuracy and how accurate local users expect these small area estimates and projections to be. Building on previous findings from this research, the third section of this chapter focuses on the strategies employed by local users to manage expectations of accuracy when presenting these figures to less experienced users, such as policy makers and elected officials, and the approaches taken to make these population statistics more believable or realistic. Following this, the fourth section will explore the role of technical knowledge, and in particular, the way in which a lack of understanding regarding the differences between estimates, projections and forecasts may result in these statistics being misused and how this may influence perceptions of accuracy. The fifth section will explore the way in which area-specific knowledge held by local users may help to improve the accuracy of small area population estimates and projections by ensuring that local demographic trends and the physical geography of an area are taken into account, should these issues have the potential to influence the accuracy of population statistics. The final section will examine the main barriers which may prevent local users from producing their own population statistics. While the previous section deals with how local knowledge may improve the accuracy of population statistics, this section examines the main issues as to why local users may find it difficult to produce their own population statistics, including a lack of access to resources and the challenges associated with cuts to local government funding which impact upon staffing levels and training opportunities.

7.2: WHO USES NRS POPULATION STATISTICS?

One prominent finding from this research found that the population figures released from NRS appear to be very widely used across a number of organisations and sectors throughout Scotland. Participants of this research had a wide range of backgrounds and experience. A majority of respondents to the questionnaire used in this study worked in local authorities or in the health service, while there were also individuals who worked for other government organisations as well as in the private and third sectors. This survey found that the users of NRS population statistics primarily worked in local government (58%) while others worked in public sector organisations such as Police Scotland, the NHS and the Scottish Environmental Protection Agency. As well as working across a range of organisations, participants of this research were found to work in a wide range of departments within these organisations.

Figure 7.1: Word Cloud: Which department do you work in?

Figure 7.1 shows the most common words which emerged when asking participants of the questionnaire which department they worked in, within their organisation. While in some cases departments focused on more than one area, e.g. Housing, Planning & Regulatory Services, the word cloud shows the sectors in which users of population statistics are most frequently employed. The most common departments mentioned by participants were related to health care and housing, followed by various combinations of planning, regeneration, development and research which were frequently combined into one department. This wide variety of departments across a range of organisations, demonstrates how extensively population estimates and projections are used, particularly in the provision of public services such as schools and healthcare, emphasising their importance as a planning tool. This was highlighted further during the in-depth interviews with users, which revealed a variety of tasks which featured the use of population statistics.

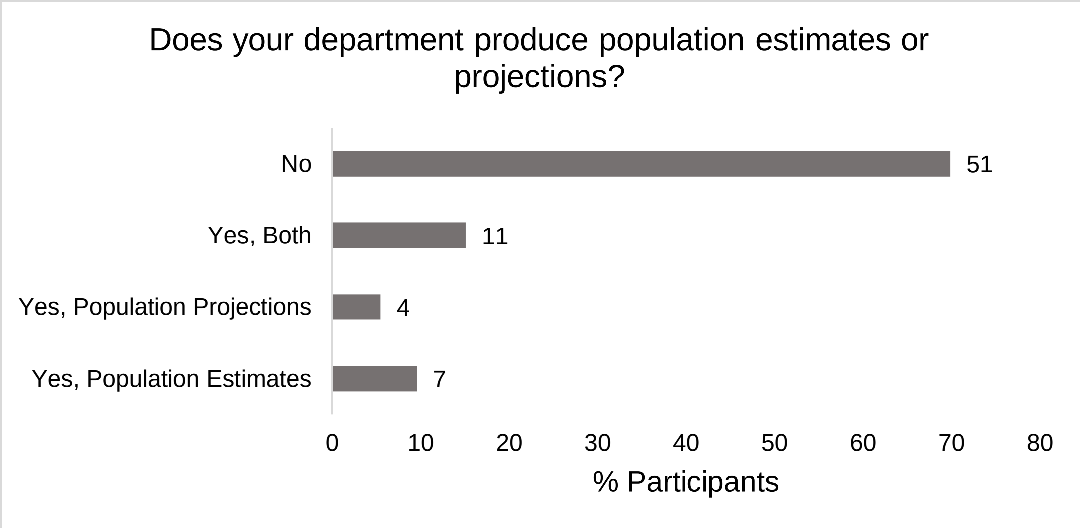
"Well, we use them fairly extensively, as you can imagine, and we work right across the Fife partnership, with police work, the NHS, as well as Fife council services. Mainly we use it to identify trends and so on, but we also use it for school estate planning, in particular we do a lot of work around that. So we identify how many classrooms will be needed and that's done on a sort of ongoing basis because developers will come up with proposals and we will need to assess whether there's capacity for new housing developments and so on. So population projections are a major aspect of that. They're also used in crime prediction, basic demographics, strategic planning, strategic assessments of Fife. So we use those an awful lot, I could go on and on and on, we use them a lot." – Michael

"I have used population projections for facilities planning and assessing retail demand. I've also used them to gauge the proportionate scale of growth in different settlements which is useful in deciding potential for further housing land allocations. I'm aware that they have been used for transport modelling, but I'm not directly involved with this." - Steven

These two accounts from participants in this research provide an insight into the extensive use of population statistics in the public sector. The excerpts from Michael and Steven present population projections as a valuable tool which help to inform planning and decision making across a range of sectors from housing to education and crime. These descriptions from interview participants reflected feedback from respondents to the questionnaire, who provided a wide range of examples of how population estimates and projections were used in their work. These ranged from organising polling stations to estimating demand for English as a Second Language services, as well as being used in research into areas such as deprivation, diet and health. The extent to which these statistics are used, highlights the importance of their accuracy and usefulness at a local level. While national or sub-national statistics may be more reliable and easier to produce, these accounts from local users suggest that small area, sub-council population estimates and projections are an important asset to local planners in many aspects of their work.

While population estimates and projections produced by NRS are widely used across Scotland, results from the questionnaire found that there were very few participants whose work places produced their own population data, suggesting that there is a reliance on centrally produced statistics. When respondents were asked whether their department produced their own population statistics, it was found that around 70% of the 73 respondents indicated that their departments produced neither population estimates nor projections.

Figure 7.2: Participants who produce population statistics



Findings in Figure 7.2 shows that very few of the participants in this research produce population statistics of any kind. Of those who did work in departments which developed their own data, most were likely to produce both estimates and projections, while for departments who produced a single type of population statistic, it was more likely that they would produce estimates compared to projections. These findings are in line with other research conducted for Scotland in this field. Findings from a NRS survey (NRS, 2018) found similar results, with 71.4% (n= 45) of respondents indicating that they had not produced their own small area population projections, based upon a sample of 63 users.

As well as relying on NRS produced population data directly, findings from this research suggest that even local authorities which produced their own population projections used NRS figures to some extent. Using NRS projections as a reference was one way in which local authorities used NRS data in the production of their own estimates and projections. When participants were asked how they evaluated the projections they produced, the most frequently used evaluation method was a comparison to NRS figures with 46% (n=13) of participants indicating that they used this method. This comparison was also an important benchmarking tool for respondents who produced their own population estimates where 26% (n=19) of participants responded that they compared locally produced estimates to NRS figures.

As well as an evaluation tool, some participants indicated that they used NRS population estimates and projections directly in the production of their own estimates and projections, constraining their own figures to NRS sub-national or national estimates, to improve accuracy and consistency.

"Where we need to produce projections is at a lower level than NRS provide, we'll connect it back to the NRS projections at the higher level, to correct that anomaly. The last thing you want is to get into a dispute with a developer over a projection or

something like that, part of that is risk management. We have looked at how NRS projections change year-to-year and that kind of stuff so we keep that in mind as we do our own projections.” – Michael

This account by Michael illustrates the importance and usefulness of NRS projections, even in organisations which produce their own population statistics. While it may be useful for councils to produce their own figures, there is also a risk that it produces conflict between analysts and planners or between different departments within the council. By using NRS projections as a reference or constraining locally produced statistics to NRS outputs, respondents reported that this helped to make estimates and projections consistent and potentially reduce conflict.

Overall, findings presented in this section, suggest that NRS estimates and projections are widely used tools across a number of different organisations and departments in Scotland with the majority of respondents reporting that their departments do not produce their own estimates or projections. In this context, it appears that the NRS figures are heavily relied upon. In addition to the lack of local organisations producing their own in-house statistics, the use of NRS data by local authorities, who do produce their own figures, either as an evaluation or constraint tool, further stresses the extensiveness of NRS statistics within local authorities. This widespread use of NRS estimates and projections highlights the importance of evaluating the accuracy and usefulness of their data.

7.3: ACCURACY MATTERS

As the preceding analysis in this research has been focused upon quantifying the accuracy of both population estimates and projections, one primary theme which was explored in this chapter is the value and usefulness of population statistics and the extent to which accuracy matters. As discussed previously, population statistics, particularly the centrally produced NRS statistics, are widely used in Scotland across a range of organisations and specialist areas, this section seeks to explore how population statistics are a tool for planning and policy making, as well as how users accommodate error.

Participants interviewed in this research revealed that there are many scenarios where they require detailed sub-council level population data when planning for the future. While previous research has shown that error is inversely related to population size, with error high in areas with smaller populations (ESRI, 2007:4); results from this research emphasise, while accuracy for small area estimates and projections is more difficult to achieve, highly accurate small population statistics are vital for local planning and policy making.

“I do the school roll forecasting as well and for some islands, if one family moves in or moves away then you’ve just lost your entire forecast because if they take three kids with them then it can either double the size of the school, or half the size of the school or in some cases, remove the school entirely” - David

“I think they wanted to put in an extra water pipe or something and if the population got over a certain number, I think about 150, they needed a new water pipe and it was trying to work out how close to 150 it was, but it’s a complicated exercise.” - Catherine

“We have a particular issue here with, if there’s an extra one or two pupils you could need a new classroom, that’s just nonsense, nothing’s accurate enough to do that, yet we’re having debates about the sort of fine resolution of the projection when we don’t know to that resolution, we just don’t know.” – Michael

These accounts from participants show the complicated relationship between the requirement of small area population estimates and projections to be accurate, and the struggle to achieve this level of precision. Many of the planning tasks associated with small area statistics are very population sensitive, with the viability of resources hinging on the balance of a small number of individuals. The issue of school roll planning, discussed by both David and Michael, is a clear example of how planners feel they need to be aware of future population sizes to a high degree of accuracy. Under legislation introduced in 2010, primary one class sizes were capped at 25 pupils in schools in Scotland (Scottish Government, 2018), demonstrating how planners must consider what the future population may look like at a micro-level, in this case, when planning the number of classrooms and teachers required to both accommodate the population and comply with legislative restrictions.

Many of these micro-level planning decisions are not only the most difficult to provide accurate figures for, but also tend to be the most politically sensitive and more likely to capture public imagination. One case study which illustrates this can be seen in the press reaction to a report covering school place provision in Scotland.

A report released by the Scape Group in 2019, stated that by 2021, there would be an increase of 13,600 secondary school age children across Scotland, resulting in 435 additional classrooms, or 13 new schools. This report was covered by both the national and local press in Scotland, with the Herald reporting that; “*Population surge sparks 'urgent need' for extra school classrooms”,* while local papers such as Tayside’s Courier (2019) and Aberdeen’s Press and Journal (2019) also covered the issue for their areas, both describing a ‘crisis’ and ‘critical shortages’. Within these articles, some representatives of local authorities and local authority bodies such as the Convention of Scottish Local Authorities (COSLA) explained the role of population projections in informing planning, meant that increases were already factored in to decision making, while others disputed the Scape Group's (2019) conclusions, stating that they were out of line with the councils' own projection figures. While the main focus of the newspaper coverage was the shortage of school places for secondary schools, findings from the original report also commented on the provision of primary school places over the same period. The report stated that "*With 19,700 fewer primary school pupils by 2020/21, there is no requirement for new primary schools*" (Scape, 2019:15), a change that was greater than the 13,600 increase of secondary school aged children. While there were significant demographic changes both the in numbers of primary and secondary school aged children across Scotland projected by this group for 2020/21, the reduction in the number of primary school pupils was not reported in the newspapers in the same way as the increase of secondary school pupils. The Herald (2019) article did include a sentence which acknowledged the fall in primary school pupils; *"Overall, Scape's report, The School Places Challenge 2019, said Scotland's school-aged population was set to increase by 4.8% over the next two years – although numbers will decline in primary."*, however the article was primarily focused on the population increase and the potential insufficient provision of school places, while the local newspapers (The Courier, 2019, The Press and Journal, 2019) only focused on the pressure caused by the increase in secondary school pupils.

This example, highlights the scrutiny that demographic change is subject to, depending on whether councils are considered to be prepared for potentially problematic changes in the population and can respond to population change in a timely and effective manner. During focus group discussions conducted as part of this thesis, one participant commented that error was less important when the reality was 'better' than the scenario projected, with more scrutiny when a projection fails to capture an adverse change in the population. This view seems to encapsulate the approach to the reporting in this story. As Haub (1987:4) writes, *"Since many people for whom demography is not a daily concern receive their information through the media, the way projections are interpreted in the press or television is of considerable importance*". This means that when perceived miscalculations in population projections lead to potentially adverse conditions for the public, local authorities must respond with robust population data to demonstrate how the figures were produced and justify their decision making.

Despite it being extremely difficult to produce detailed and accurate small area population statistics, there are many cases where the level of detail sought after by some planners cannot be reliably captured in population projections, particularly over a lengthy time frame. In these cases, analysts and users must also be equipped with the skills to explain the limitations of population projections and advise users of the degree of accuracy which can be expected from small area population figures. By providing the robust and reasonable population statistics along with a transparent methodology and knowledge of potential factors which can influence accuracy, local authorities and other organisations who make decisions based upon population projections can justify their policy making and better counter scrutiny when unexpected changes lead to challenges in providing public services and resources.

7.3.1 Users Perceptions of Accuracy

This desire for highly accurate population figures was also found in the responses from participants of the questionnaire. As part of the survey of users of population statistics, respondents were asked what level of error could be present in (sub-council area) population estimates and projections and would still be considered useful.

Table 7.1: Users Accepted Margin of Error: Descriptive Statistics

	n.	Max.	Min.	Mean	Mode
Population Estimates	39	25	0	7.34	5
Population Projections	38	30	0	10.32	5

Table 7.1 shows a summary of the responses from participants when asked to provide what level of error could be present in population estimates or projections and remain useful. It can be seen from Table 7.1 that on average, users felt that they would accept higher levels of error for population projections compared to estimates. However, for both estimates and projections, the most common margin of error which was selected by participants was 5%, with 31% of respondents indicating that this would be an acceptable margin of error in population estimates, and 16% indicating it would be an acceptable level of error in projections, before the data would no longer be useful. Examining these responses further, it was found that in many cases (58%), participants believed that there should be the same level of error present in both population estimates and projections.

By comparing these responses given by participants to the levels of error found in the evaluation of population estimates and projections presented in Chapters 5 and 6, it can be seen how closely users' expectations of accuracy match the true precision of these statistics. Firstly, looking at the age-specific population estimates, it was found that for all methods, the error exceeded the average level of acceptable error, of 7.34% given by participants in this research. For methods used by statistical agencies (the Cohort Component, Ratio Change and Average methods), the error ranged from 7.41% to 15.04%, while higher levels of error were present in estimates produced by the simpler methods. This means, that not only did all the age specific population estimates in this study produce errors in excess of the 7.34% average given by participants, but also the 5% acceptable level of error which was the most commonly given response.

When examining the projection methods presented in Chapter 6, it was found that the accuracy of population projections more closely reflected the level of error which users' felt was acceptable. When examining the error present in the age-specific population projection for the final year of a five-year projection, it was found that the average error across all ages and methods ranged from 2.30% to 7.50%. This range was well within the average of the level of acceptable error given by participants of 10.32%.

While the levels of error which users felt was acceptable was in line with the range of error found in the five-year projections produced for this research, responses from the questionnaire also suggested that there was no relationship between the length of the projection period and acceptable levels of error. This means that, in some cases, participants who indicated they would like projections spanning twenty years ahead or more, would want these projections to be as accurate as population estimates for the same areas. The results from this research presented in Chapter 6, would suggest that this expectation would be unreasonable, with error across all methods and age groups increasing year on year over the course of the projection period. It would therefore be reasonable to conclude that a projection twenty years in the future would be less accurate than a population estimate which aims to capture the current population size based upon the most recent data. The attitudes captured in this research may suggest that users may need to be made more aware of the limitations of projections, and in particular the shelf life of a projection as defined in Chapter 6.

When discussing the role of producers of population projections when ensuring data is used effectively, Keyfitz (1981:579) explains, *"Demographers can no more be held responsible for inaccuracy in forecasting population 20 years ahead than geologists, meteorologists, or economists when they fail to announce earthquakes, cold winters, or depressions 20 years ahead. What we can be held responsible for is warning one another and our public what the error of our estimates is likely to be"*. This view encapsulates the approach required to successfully communicate population projections to users in order to ensure that they are used appropriately. Although technical information is provided by NRS as part of their statistical releases, detailing how the statistics are produced and potential limitations, results from this research suggest that more could be done to manage users' expectations of accuracy, particularly for sub-council area data. Wilson and Rowe (2011:234) describe this expectation management of users as; "*A difficult balancing act here, of course, between honesty about likely error on the one hand and the appearance of competency and professionalism on the other. It is important to stress to users that there are many factors affecting local demographic change which are essentially unpredictable, and that similar evaluations of forecasts from economics, marketing, transport and other disciplines also reveal large errors"*. By providing a greater insight into the limitations of population estimates and projections, it would not only help to change the attitudes of users when projections do not reflect reality, it can also help to improve planning decisions, as users make more informed choices, factoring in the potential for error. This is a view supported by Smith et al (2014:364) who state that; *"Data users should be aware of these errors before making decisions based upon population projections. Projections that extend very far into the future simply cannot provide highly accurate forecasts. This may be disheartening news for* *users of population projections, but it is a realistic portrayal of forecast, given the current state of the art"*.

7.4: MANAGING EXPECTATIONS

There have been many suggestions in previous literature in this field regarding how to manage non-expert users' expectations of the accuracy of population projections and present them in a way which makes them appear more realistic or believable. This section will demonstrate how participants found various methods of increasing confidence in the population statistics they are presenting, as well as their thoughts regarding methods suggested in previous research.

One approach, which has been suggested in previous literature (Wilson & Rowe, 2011; Ahn et al, 2006) for counteracting uncertainty in population projections was by providing variant projections. Variant projections are described by Ahn et al (2006) as the main way to address uncertainty, describing them as scenarios without stories attached. In these projections, in addition to the main scenario, additional outcomes are included which take into account alternative birth, death or migration trends (Nash, 2017) e.g. projections with high migration and low migration variants attached. Sawyer and Bassarsky (2016) characterised these high and low variants as the upper and lower bounds of realistic projections, indicating the "margin of uncertainty" present. While some demographers suggest that variant projections could help users understand the possible range of the future population, some, such as Wilson and Rowe (2011) explain that these types of projections have been deemed meaningless by demographers. This was a sentiment echoed by participants in this research.

"For planning purposes, you want one figure, you have to say 'in that scenario that's what would happen' but at some point or another you've got to come down on a figure, 'we need to build 500 houses and the population will be such and such' because that's what it comes down to in the end. Certainly in the early stages of the planning process, we certainly looked at alternatives but eventually you have to come down on one side or another of what you're aiming for and sometimes that is partly a political position." - Catherine

"*I would always ask people what they intended to use it* [the projected population figure] *for, sometimes people want to know projections for a certain year, maybe 20 years on which is the sort of limit for normal population projections, just to show they have researched the matter and can quote a certain figure in a report to show they've done their homework and really, you know from the context they're speaking of it's not actually going to be used but they've taken the trouble to find out what the official figure is. See what I'm getting at? It's not going to be of any practical importance but they need to know what the government, the official government forecast is for the population at a certain time"* - Peter

It was generally felt that planners and policy makers wanted a definitive figure to plan towards, with the attitude being that if the local authority was beginning a new housing development, a range of potential population figures was neither helpful nor useful when making decisions or implementing policy. These findings are further supported by previous research conducted by the UN. In a survey of their users, the United Nations Economic Commission for Europe (UNECE, 2018) found that many respondents cited that the most common challenge that was met when communicating the uncertainty present in population projections to their users, was that they were interested in only one projection scenario, with a third of the respondents indicating this was an issue. This research by UNECE (2018) also found that common issues experienced by their respondents also reflected accounts given by participants in this current research, particularly that less experienced users have little knowledge regarding projection uncertainty, and the tendency for projections to be interpreted as precise.

While statistical agencies, including NRS and ONS have recently begun to provide variant projections to provide users with more information, views from the participants in this research suggest that these variants may be unhelpful and could be more likely to muddy the waters surrounding planning decisions rather than providing clarity. Wilson and Rowe (2011) expanded on this further, explaining that providing variant projections only results in users inquiring how likely each scenario is, with little evidence to have confidence in any potential outcome. While variant projections may aim to provide a more realistic range of possible outcomes, without a probabilistic approach, which includes a likelihood of a certain scenario emerging, these variant projections may overwhelm users with additional information, or be ignored completely. Although these variant projections are produced with the intention of providing more data for users to make informed decisions, results from this and previous research has found that users are generally more interested in a single deterministic projection. Keyfitz (1981) explains that when users who are only interested in a single scenario are presented with several variant projections, they tend to focus on the middle variant, interpreting it as the most likely. This may suggest that while the statistical agencies have worked to provide these variant projections, they may not be employed by their users to their full potential.

While the value of variant projections as a tool to indicate uncertainty, has been debated amongst demographers, one of the participants in this research has developed their own method for increasing confidence in population projections., David shared his strategy of providing projections in the context of population change which had been observed in the past, which had a positive effect, winning over some doubting councillors.

"If you show the history of it they're actually more inclined to say 'fair enough, that's where we've been'. So a lot of the presentations I do with the public and stuff is very much starting at [19]*81 and working my way forward and saying this is year by year how it's changed. So that's a good way of selling it, I think that's worked quite well. And I've got figures for some islands back to 1951, 61 so you can kind of show the 10 year gaps but '81's a good one for us to kind of start with, it's 36, 37 years ago,*

it's not that far back to go, to be outside of living memory, it's close enough to the modern era to be, in demographic terms, to be not that long ago so, certainly we don't have age breakdowns for that, but we do have the actual number for the population and that's certainly been successful. I've had fewer people challenging it since I've been showing people those sort of figures than I had previously." - David

In this account, David explains how past population trends help to put the future, projected population change in context for audiences. While in isolation, large increases in the population would be met with scepticism, in this example placing large increases into an historical context, where that kind of change has occurred previously, allows the audience to understand that the projected trends are possible. In addition to providing historical demographic changes, David also emphasised how helpful it was that the figures he used were within living memory, allowing most members of the audience to reflect back on their own experience, potentially allowing them to reflect on how demographic changes emerged based upon political and social trends.

While variant projections have been advocated as an approach to aid users' understanding of uncertainty by providing a range of realistic scenarios, this method has also been widely criticised for complicating decision making, providing multiple potentially conflicting projections. These criticisms were echoed by participants in this research, with interviewees describing how planners and developers seek a single figure to plan to or to report. In contrast, the experience of David suggests that challenges from non-expert users are reduced when projections are put into a historical context. The key difference between these two approaches could be how they help users to interpret the data. The adjusting of assumptions in variant projections may lead to confusion for users, leading to difficulties in interpreting what each of the variants are describing. O'Neill et al (2001) described this saying "*The approach also has several weaknesses The most important is that if no specific level of uncertainty is associated with the alternatives, it is not possible for users to interpret the precise meaning of the ranges presented".* In contrast, by presenting future projections in the context of changes in the past, users have a reference point which is routed in a reality that they have experienced and lived through. Here, the research presented in Chapters 5 and 6 could prove useful to users by providing an indicator of how accurate historical population estimates and projections have been for their areas.

7.5: TECHNICAL KNOWLEDGE

As well as the issue of realism and uncertainty, one of the challenges in presenting population statistics to non-expert users appears to be the confusion or a lack of understanding of the technical terms used. While demographers and direct users of population data, such as analysts and statisticians may be able to differentiate between terms such as estimates, projections and forecasts, casual users infer the same meaning from each of these terms. This gap between how users and demographers interpret certain technical language frequently used in relation to population statistics will be discussed in this section.

Findings from participants in this research supported assertions made in previous studies which suggested that when projections are presented to users, they are interpreted as forecasts. Though the participants who were interviewed in this research appeared to demonstrate a clear understanding of the difference between projections and forecasts, most felt that those to whom they were communicating the projections, did not see the distinction between the two concepts.

Interviewer: *"and do you find when you speak about projections versus forecasts, people can differentiate between the two?"*

Michael: "*You're joking, no we very often have to explain the difference and even then I'm not always convinced that they will really get the difference."*

"I think to be honest, it terms of our elected, our councillors, even our run of the mill staff, they see a figure as a projection, they wouldn't know what the difference between a projection and an estimate was. The words are almost interchangeable, I think forecast, you could throw forecast in there as well and if you said any one of those things they would think you're talking about the same thing."
"People that have not got the background in it just see 'projection', 'forecast', as one word for numerous different things, so there's a lack of understanding and to be honest, because of that lack of understanding, even if you explained it, I don't think there would be much of a 'oh yeah' more of a 'fair enough', you know a figures a figure and if you are someone who they see as an expert in that area give them a figure, they're not bothered whether it's a forecast or a projection or anything else." – David

These quotes from interviews with participants demonstrate that the non-expert users not only find it challenging to differentiate between estimates, projections and forecasts, but even struggle with the terms once they have been explained. These accounts highlight an interesting issue which links back to the theme of the perceptions and interpretations of uncertainty. If users view population projections and forecasts as one and the same, problems arise as this could have an impact on how the data is perceived and used. These findings suggest that there is a knowledge gap between expert and non-expert users regarding the technical language that is used to refer to population statistics. While this lack of distinction between the terms used may be thought of as insignificant, there is potential for the misunderstanding to have an impact on the effectiveness of population projections. While projections continue past trends, local users are free to include assumptions which take into account their future plans and developments. If users assume that these official projections are forecasts and therefore include local plans and developments, there is a greater potential for error, or perceived error, as demographic changes as a result of these developments not being taken into account. Without developing a strategy to increase lay-users understanding of what these projections show and their limitations, this problem will continue with population projections being misinterpreted as forecasts, leading to mistakes in planning and service provision.

Overall, the findings from this section of the research demonstrates the importance of accuracy in the work of planners and policy makers. One of the main findings of this research was that while front line users such as analysts and researchers, felt that accuracy was important for making micro-level planning decisions for small areas, they understood the limitations and challenges associated with estimating and projecting populations at neighbourhood level. Although the participants in the interviews fully understood the challenges associated with small area population statistics, several of whom had produced their own data, their accounts of communicating population statistics to colleagues and councillors who were less familiar with the data was revealing. The main themes throughout this section highlighted the potential for conflict between expert and non-expert users, as well as the difference between demographic changes which were happening in reality and those that were perceived to be happening. These finding suggest that, while individuals who work closely and directly with population data, on the whole, demonstrate an awareness of the limitations and potential for error in population statistics, more work can be done to manage the expectations of less experienced users. If this management of expectations is successful, along with increased knowledge of how projections should be interpreted, it could mean that, even when errors do occur the impact is reduced, as the potential for error has been taken into account by planners at a local level.

7.6: LOCAL KNOWLEDGE

While participants in this research felt that NRS produced population projections to the best of their ability and to a high degree of accuracy, one prominent theme which emerged throughout the interviews was their view that there were some local issues for which it was not possible for NRS to account for in their data. This section will explore to what extent local knowledge can be used to evaluate population statistics and identify potential sources of error, as well as how this local knowledge can help to inform the methodology and assumptions used by NRS in their analysis.

When looking at the role of local knowledge, results from the questionnaire found that local knowledge or ‘sense’ check was a commonly used evaluation method, with many respondents using knowledge of their area to assess the accuracy of population estimates and projections.

Figure 7.3: User Evaluation Methods

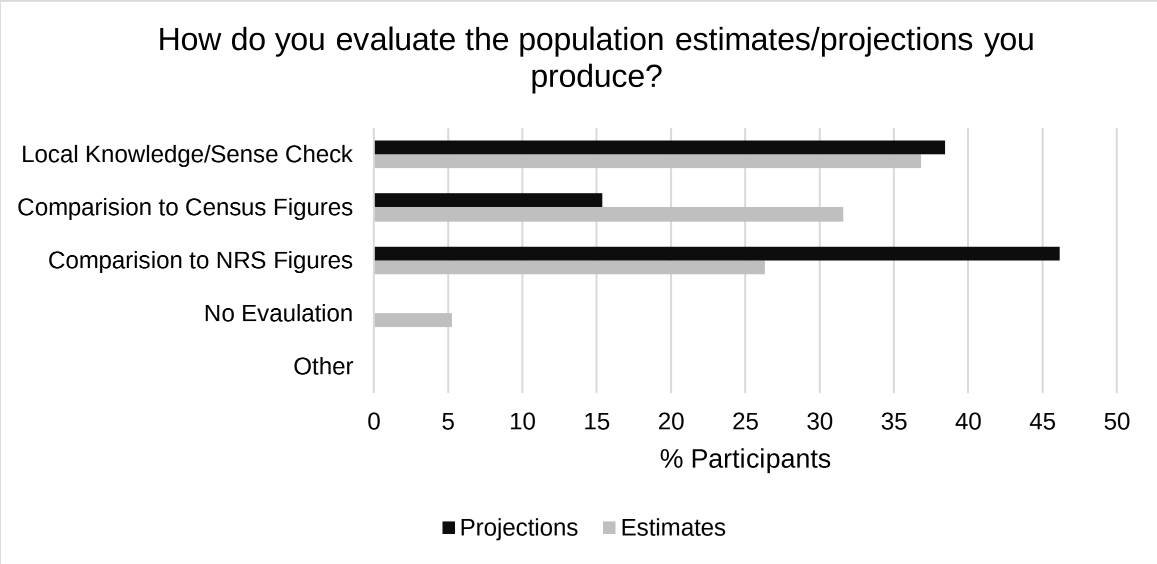


Figure 7.3 shows the responses from participants of the questionnaire when asked which methods they used to evaluate the population estimates and projections they produced themselves. As these questions were only shown to participants who produced their own data, it is based upon a small sample size (estimates, n=19; projections, n=13). Responses show that local knowledge or sense check was the most frequently used method for evaluating population projections, with this option more popular than comparing locally produced projections to those produced by NRS or the population recorded in the census. The use of local knowledge was also popular for producers of population estimates, as it was cited as the second most used evaluation method following a comparison to NRS figures. This use of local knowledge in the evaluation of population data, produced both in-house by local authorities and centrally by NRS, was also a theme which appeared frequently throughout the in-depth interviews.

"In this area there were significant housing allocations from the 2003 Local Plans onwards. Due to infrastructure constraints and general delays in getting new sites started and probably inertia in the data collection system; these policy decisions were not reflected until comparatively recently in NRS projections" – Steven

"*I'll give you an example, in the 2001 census when the figures came out there was a huge drop in the population in Ullapool, that was recorded and that was picked up in the press as all doom and loss in Ullapool which just didn't sit right with people because there had been a lot of new developments and new housing in the Ullapool area and when we dug a little deeper into it and spoke to people in the area we found that in 1991, a former soviet Klondiker, a large fishing vessel, had been tied up in Ullapool harbour since the fall of the Soviet Union, since the collapse of the Soviet*

Union and all the sailors had been there for so long, been looked after by the fishermen's mission that the boat was given a postcode and they were included in the '91 census and they'd all gone by 2001 but the sheer number of sailors there boosted the population numbers in the 90s then they dropped in the 2000s" - Stuart

The above extracts from interviews with local users of population statistics highlight how local knowledge can be used to identify potential limitations of centrally produced statistics, by employing their familiarity with the area and the distinct character, quirks and local developments associated with it. In these interviews, participants acknowledged that in a majority of cases, the areas where they could identify potential sources of error were unavoidable, based upon the methodology used by NRS. The example by Stuart of the Soviet seamen provides a particularly powerful example of how strange and unforeseen events can impact upon the validity of population statistics. Throughout these interviews, this theme of local knowledge was developed, with participants emphasising how this knowledge was honed and developed through the personal experiences of team members within the departments, as well as through relationships with the local community. In many cases, participants in this study were able to identify potential issues in the population data due to their position as part of the community, as well as personal and professional links to other local agencies.

"We are a big beast of an organisation within the Highlands and Islands and we have long tentacles into every community, you know, we reach enough to know all the main businesses in an area reasonably well, and the main community groups reasonably well so we've got a good idea of what's happening or we're two or three phone calls away from being able to speak to someone who, with authority, will be able to comment on the robustness or reliability of the figures." - Stuart

"*We've people here who have a lot of knowledge of local areas because they've worked in this job for so long, that's actually expertise I'd be frightened to lose, so we do have the ability, people who can scan their eye over it for a couple of hours and identify if there's anything wrong with it."* – Michael

While previous chapters have focused upon a purely empirical evaluation of population estimates and projections, focusing on the performance of past releases, these accounts demonstrate how local knowledge, obtained through observation and experience, can also be used in the evaluation of these statistics. This evaluation is also a more immediate way of identifying potential error, instead of comparing past estimates or projections to what was observed. This means that any potential issues may be taken into account when the data is being used.

As well as acting as an evaluation tool following the release of population data, local knowledge can also play a role in informing the approaches taken by NRS, in order to eliminate any potential problems in the future or to make the data more suited to a particular area. Isserman (1977) commented that "*Projections, generated merely by projecting past population trends into the future, quite likely can be improved by incorporation of the knowledge of local officials regarding such factors as the spatial pattern of development, available land, and transportation investment*". This view, that local knowledge can play a role in improving the quality and usefulness of population estimates and projections, appeared to be shared by some participants in this research, some of whom provided examples where their knowledge was used by NRS to change their methodology and improve their service.

"[Anonymous] *who used to do the Glasgow City Council ones got them* [NRS] *to change their death rates, something to do with death rates I think, because what happened in Glasgow, was that, because they've got quite a lot of deprivation and death rates appear to be high, you hear that all the time that the people of Glasgow die five years younger than elsewhere. But what tends to happen is that if you actually get to 65 in Glasgow, it doesn't matter if you live in a good area or a bad area you're pretty tough and the differential, it was a differential death rate, that's what it was. The differential death rate for the older generation was a lot lower that it was for the younger population because a lot of issues with the deaths in Glasgow is due to, young men in particular, dying of drug addiction, violent death and suicide and these kind of things which are associated with deprived areas but if you make it to 65 in a deprived area, you're tough and the differential between someone who lives in a deprived area whose 65 and someone who lives in a wealthy area who is 65 is much less than it was for younger age groups. So applying the differential across the board didn't really work and NRS changed that."* – Catherine

"I think the way that the government sometimes when it breaks down Orkney into different areas, data zones, SIMD, data zones and various things, there have been ways in which the government has broken Orkney down and it hasn't worked so it's while we've done POPGROUP and other things that we've gone to the government and said 'this is how we want you to break Orkney down now'. Because locally we know how that works. In the 2001 SIMD data zones, they split one of our islands into two and they combined half of the island with another island and the other half … It doesn't make, for us it doesn't make any sense because we know how they all work, but after 2011, the data zones are much more, they're as useful as they can be. Some islands are still grouped together, we'd like them to be independent but we know there's not enough population on them for that to work so, yeah, it's certainly improved, the 2011 alignments are certainly a lot better than the 2001 ones were but that's on the back of us going to the government and saying, 'this doesn't work, can you change it to this please?' and they've taken that on board so they are being good with that." – David

These accounts illustrate how an individual's knowledge of their area can play an important role in the development of estimation and projection techniques. In the example given by Catherine, the importance of area characteristics is highlighted, with Glasgow being a prime example of how the distinctive character of an area, particularly when there is such a diversity of small areas within one council, may mean that projection techniques may need to be adjusted. In particular, the assumptions used to produce population projections may be influenced by factors which are specific to an area. While it may be tempting to assume that all the sub-council areas within a local authority will share some characteristics, each small area will have its own distinct character and, in some cases, these characteristics may influence the assumptions which should be used when producing population projections.

This view that assumptions used in the production of population projections can be improved by local knowledge is shared by Rayer (2008:426) who stated that, *"While projecting small and/or rapidly changing places will always be a challenge, a careful choice of methods, base data, and assumptions, when combined with the application of local knowledge, will lead to the best possible projection outcomes".* While, as previously discussed, local authorities can adjust the population projections to include upcoming developments or policy decisions, in Catherine's case, local knowledge was used to inform the underlying assumptions, e.g. mortality differentials, that are used to project forward past trends. These assumptions are the foundation of any population projection and are the basis on which the whole projection is built. This suggests that it is more difficult for local users to incorporate their knowledge of rates of fertility, mortality or migration on a post hoc basis. Although at sub-council level, local knowledge may be the most difficult factor to incorporate into centrally produced population projections, it could be argued that it could have a positive impact upon the accuracy and usefulness of the output by improving the underlying assumptions.

As well as informing the assumptions used to create the population projections, local knowledge about the reality of how the population live on the ground can also help to inform agencies, such as NRS, as to the best way to define the sub-council areas, in a way that is meaningful. This is highlighted in the example given by David, who described how, initially, the 2001 data zones defined by NRS did not make sense in practical terms. He discusses how the data zone boundaries divided islands in half, with some examples of where these half island areas were combined with half of other islands. There are multiple examples of this regarding island communities, with representatives from these island councils giving examples as part of a consultation held by NRS when the 2011 data zone boundaries were being defined (Scottish Government, 2014). A representative from Orkney council explained how the island of South Ronaldsay was one area where the island was split between two data zones, while two smaller islands Graemsay and Gairsay were grouped with the Mainland data zone rather than the other smaller islands in the Isle data zone. This treatment of the islands was also raised by a representative from Argyle and Bute who stated that;

"*The only island in Argyll and Bute where the data zone boundaries coincide neatly is Bute. All other islands are either linked with other islands or with the mainland. Again, this makes understanding our communities difficult. For example, data zone S01000755 (DZ350045) includes part of Islay, the whole of Jura, and Colonsay. There are minimal transport links between Islay and Colonsay (one ferry in each direction a week in the summer). The natural linkage here would be between Colonsay and Oban. (This does not, however, align with the political / administrative boundaries used by the council, which do, in fact, link Colonsay with Jura and Islay.)"*
– Chris Carr (Scottish Government, 2014)

The examples given in this consultation support the account given in the interview by David, and further suggest the value of local knowledge in filling in the gaps in understanding, that centralised agencies may have. This issue appears to be more prominent in island communities were it may be more difficult for remote analysts to understand the way in which smaller islands interact with one another through transport links or share particular characteristics. This is where knowledge of both the local population and the infrastructure plays an important role in helping central agencies provide meaningful data.

Findings from this qualitative aspect of the research highlights the value of local knowledge and place-based experts in the evaluation of population statistics, both in terms of their final output as well as the underlying assumptions used in their production. While the empirical evaluation of population estimates and projections can provide a measure of accuracy by comparing past projections to reality, feedback from users based within the areas for which the data is produced can help to explain why inaccuracies may occur. A report by ESRI (2007) describes how technique alone, does not ensure accuracy but that the underlying assumptions must be of a good quality. In their recommendations for increasing the accuracy of population projections, ESRI (2007:2) suggest *"Submitting forecasts to knowledgeable persons in the forecast areas for assessment".* This recommendation acknowledges the role of local experts in assessing and evaluating the accuracy and usefulness of population statistics. While the role of area characteristics has been explored to some degree in previous chapters of this research, local analysts are in a unique position to assess and recognise potential events or characteristics associated with their area which could potentially be influencing the accuracy of population estimates or projections. This knowledge is a valuable tool in the evaluation of population statistics and should be drawn upon to identify and rectify any potential issues present in both population estimates and projections.

7.7: LACK OF RESOURCES

While previous accounts from participants suggest that local expertise may be a useful evaluation tool, findings from this research also suggest, in some cases, local authorities lack the abilities or the capacity to provide this local knowledge. In many cases, participants in this research indicated that they were the only individual within their department, if not the council area, who specialised in demography and worked directly with population statistics, while others felt there was a lack of confidence in their own knowledge. This section will explore the current provision of demographic knowledge and skills as described by participants, as well as exploring their attitudes to producing population statistics.

When discussing the process of producing their own population statistics, many participants in this survey indicated that they did not feel confident in their skills, with isolation and a lack of support being the main reasons cited for them doubting their own abilities. Throughout both the interviews and the questionnaire, a main theme which emerged was the absence of a support system through which participants could gain reassurance or consult with colleagues. In the questionnaire, many of the participants who produced their own population statistics found the process difficult, with producing population projections seen as more difficult than estimates.

Figure 7.4: How easy did users find producing population statistics?

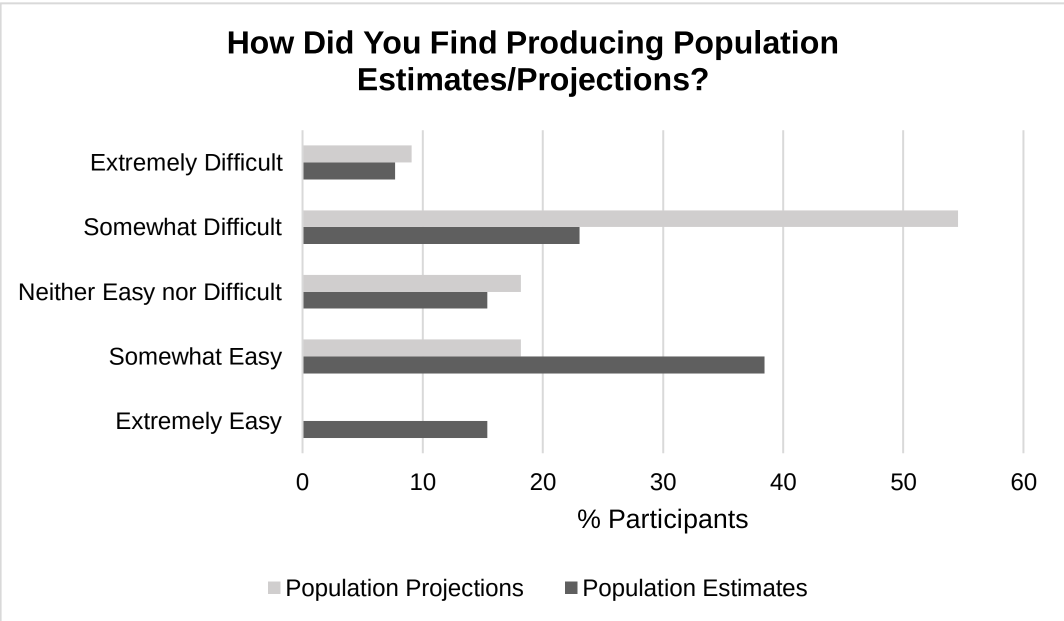


Figure 7.4 shows the responses as to how participants found the experience of producing population estimates and projections. Of the eleven individuals who produced their own population projections, 64% found it at least somewhat difficult, with none of these respondents finding the process extremely easy. In contrast, producing estimates was seen as easier with only around 31% of the 13 respondents

finding the process at least somewhat difficult and 54% finding it at least somewhat easy.

While the process of producing population estimates and projections can be a difficult and complex process, it could be argued that some of the participants' perceptions of difficulty when producing population statistics could be influenced by the lack of confidence they have in themselves and the availably of support networks. Most of the issues which respondents cited in this survey involved a lack of confidence or a perceived lack of knowledge in statistics. Interestingly, these feelings of a lack of confidence occurred regardless of experience, with participants holding many years of experience in their roles finding the process difficult, with one individual who reported they had 18 years' experience, indicating that they found the process of producing population estimates and projections extremely difficult. There was a common feeling that participants did not view themselves as 'real statisticians' while others felt that there was a lack of support.

"None of us up here are demographers, to be honest I'm not even a qualified statistician but it's something I've been interested in. I've just been told, 'Right, we're a small council up here' so it's something you get landed with. You just get told,' right now you are the subject expert so go on and figure out how to do it'. Prior to that, I was in Needs and Demand assessment. It was a document I needed to write so I had to learn the statistics and stuff. I'm an economist by background anyway, but I had to learn on my feet. I'm the most qualified of the unqualified amongst us."

- David

"It's a mix of statistical inexperience within the department and available time to produce outputs, understand them and have confidence in them" – Survey Comment

This lack of any formal training in statistics or demography appears to have a strong impact upon the confidence of individuals in this study. In turn, this lack of confidence may create a barrier for staff in local authorities, to produce their own population statistics, leading to a dependence on centrally produced data. The above accounts from participants of this research, highlight that it is not only a lack of individual knowledge which is an issue, but a lack of general knowledge and experience within departments. The comment *"statistical inexperience within the department"* touches upon the experiences of other respondents who felt that they were somewhat isolated in their role with one individual describing how they had *"no-one to bounce ideas off"* when recounting how they found the process of producing population projections difficult. This was also a sentiment echoed by participants who attended the 2016/17 Demographic Forecasting with POPGROUP course, who were consulted as part of this research, and indicated that in many cases they were the only individuals within their departments who had the knowledge to produce population projections. This training course also highlighted a desire from local analysts to both improve their knowledge and skills and to build a support base, with this training popular enough to run on two occasions.

This feeling that there were only a limited number of capable staff was a strong theme which emerged throughout this research. In many cases participants felt that, even if there was an individual or team who were experienced in working with population statistics, this knowledge was fragile and temporary, with the view that if one individual left, the knowledge would go with them.

"When I was in Falkirk, there was a girl that I worked with. Girl, ha, she's in her 70s now, who had been working in Falkirk since the '70s and what she knew about what happened and what went on in Falkirk was just unknowable and it's not knowledge that you can pass on and when she retired ten years before I did, we literary just had to dump all of the stuff she had because nobody knew what she had and nobody knew, would know what was there. I'm sure she had stuff that I could have used but I didn't know what was there so it just all got dumped and it was the same when I retired. The stuff just all got dumped because no-one else really knows what I know and there is no way to pass on that knowledge. I mean even if you work closely with people, like we worked closely for 10 years, and I still don't know all the things she knew. There's a lot of individual knowledge and expertise that just walks when people walk out the door." – Catherine

This account demonstrates the fragility and transience of the expert information which previous findings suggest is a vital tool in evaluating and improving population statistics. While some local authorities may feel lucky to have an experienced employee with extensive knowledge of the demographics and area characteristics, this knowledge does not belong to the organisation itself but to the individual, meaning that knowledge held by a local expert is easily lost when they leave their post. As previously discussed, there is frequently only a single individual who works with population data, particularly in smaller local authorities. This makes it more difficult for experienced and knowledgeable staff members to pass on their information or train their successor, as there may be no-one else in their team or department qualified. Looking at these findings as a whole, feedback by participants in this research suggest that the departments which work with demographic data and population statistics are particularly vulnerable to suffering a 'knowledge gap', whereby, expertise is lost with the departure of a single staff member. This knowledge gap may pose a major challenge to any local authority's ability to create and evaluate population estimates and projections for their area.

Catherine, who has around 40 years' experience in working in the area of demography and population statistics also reflected on recent changes, with a decline of specialists working on population issues.

" I think my concern is that the expertise in local authorities has decreased dramatically since I started working in local authorities in the 1970s where there were quite a lot of people who had expertise in this kind of area, partly because we had regional councils and district councils and the regional councils did all the heavy lifting in terms of research, statistics, and not just for population, we had a huge team in Strathclyde who did economic statistics and in Central Region we had a team who did economic statistics and nowadays we just don't have that amount of expertise in local authorities. The number of people involved in this kind of area has decreased and it's increasingly difficult for people to take time out to go to things like PAMS [Population Migration Statistics Committee] *meetings. It used to be quite accepted that you got on the train and you went to the meeting and you spent all day at it and that was fine. Increasingly nowadays you'll find people saying, 'oh you can't go' either because they don't want to pay the train fares or because they don't want you to take the time, you've got other jobs to do, that you should be sitting in your office doing your job instead of going to the meetings where you're meeting people and you're networking and you're learning and you know who the experts are and if you've got a problem you know who to phone up whoever it is you know that knows a wee bit about that particular topic. I mean that concerns me a bit but that's a much more general problem I think."* - Catherine

In this account, Catherine compares the level of research which was conducted at a local level in the 1970s compared to recent years. The role of regional, and district councils are seen by Catherine as key to the facilitation of local expertise and analysis. Prior to the restructuring brought about by the Local Government etc (Scotland) Act 1994, Scotland consisted of nine regional councils, three island councils and fifty-three district councils (Fairley, 1998), however in 1996, these regional councils were replaced with a 'single tier' system of 32 local authorities, where it was intended that these new authorities would *"inherit and exercise for their area all functions previously confided to regional, district and island councils"* (Stewart, 2012:249). While it was anticipated that all of the responsibilities held by the regional, island and district councils would be transferred to these new local authorities, Catherine's account suggests that there is less locally based research and analysis since restructuring occurred. This may also be supported by previous research into to the sources of local authority population estimates.

In a survey carried out as part of the 'Estimating with Confidence Project', Simpson et al (1997) found that 66% of regional councils in Scotland produced their own population estimates either on an occasional or regular basis. This is in contrast to the proportion of district or island councils where only 20% of areas produced their own occasional or regular estimates. This figure of 20% of district and island councils in 1991 is consistent with the findings of current research, which indicated that only around 30% of respondents work in a local authority which produce their own population estimates or projections. This suggests that the work that regional councils were doing in producing population statistics was not passed on to local authorities, with councils in 2018 producing population data at a lesser rate than the district and island councils in 1991.It could therefore be argued that the restructuring which occurred in the 1990s has had a negative impact upon the research and analysis output produced at local government level.

Previous analysis of the impact of the restructuring of local governments in Scotland supports the view that local expertise may have been impacted upon by the loss of regional governments, both in terms of skills and cost. When exploring the disruption caused by restructuring, Lloyd (1996) describes how the change from a two tier to a single tier system could impact upon the skills and experience of staff members in these new councils. Lloyd (1996) explains that part of the costs associated with restructuring would be in the passing of responsibilities previously carried out by regional councils to new local authorities where staff had little previous experience. In addition to developing skills to take on their new responsibilities, Lloyd (1996) also expresses concern that staff will also have to forge new relationships and professional connections with central government, which take time to establish. As well as costs in terms of skills, previous analysis of restructuring has also found that there was a financial cost to this change with McAteer (1997:64) explaining how, compared to regional councils, local authorities had "*smaller individual budgets and will have less control over the amount of revenue they can generate from their local tax base"*. Taking into account all these effects of the local government restructuring, it could be argued that the capacity for local councils to produce their own population statistics suffered a substantial setback with the abolition of regional councils.

While some of the loss of expertise and local knowledge may be traced back to the restructuring of local governments in the 1990s, more recent government policies may also play a role. As well as discussing the role of regional councils, Catherine also comments on the councils' aversion to sending staff to training or networking events such as PAMS, either because of financial costs or time pressures. The reluctance of local councils to finance travel and training costs could be understood within the context of local government cuts which affect councils throughout Scotland and the UK as a whole. Since 2010, local governments have been experiencing financial pressures as a result of government austerity policies with the Scottish local authority service spending falling by an average of 11.5% between 2009/10 and 2016/17 (Gray & Barford, 2018), with COSLA (2019) stating that the local government budget, as a whole, has reduced by 4% in real terms over the last five years. As well as a reduction in funding, these austerity measures have coincided with an increase in demand for services with COSLA (2019) further explaining that ageing populations and increases in individuals with complex support needs, increases pressure on local governments. In the context of these cuts, councils may be reluctant to fund travel to training courses or networking events as described by Catherine. This prioritisation of costs has been a subject of study in previous research where Gray and Barford (2018) explain that planning and development services have had their budgets cut by the most, with 53% reduction in spending observed between 2010 to 2016. This is relevant to this research, as many of the participants in this study worked in planning and development roles within their councils. Gray and Barford (2018) explain how this sector is targeted by cuts as it is seen by some councillors as an example of the *““Bloated” and bureaucratic state*”.

While population statistics and demographic data can help to inform planning decisions across the spectrum of responsibilities held by local authorities, results from this research and previous analysis, suggest that their value and importance may not be fully taken into account by councillors. This is an extremely important issue as it is these councillors who are not only the individuals using these figures, but are also those who determine future budgeting decisions. If councillors require high quality population data to inform their policies on education, health, housing and more, then they must also be prepared to fund the expertise and training required to produce them.

The issue of institutional knowledge loss and budget cuts are not only present within the demography departments in Scottish local authorities but is a much wider problem. However, other accounts in this research suggest that this issue may be particularly acute amongst staff working with population statistics who tend to work in small teams, or in some cases as individuals. While the centralised production of population statistics by NRS may lead local authorities to believe that there is no need to invest in staff who work in demographic analysis roles, current findings indicate that staff working within local authorities have key knowledge which can improve population statistics in a number of ways. With the use of population data so integral to the successful provision of a range of resources, it is vital that they are as useful as possible. This research suggests that local knowledge is one of the most important tools which exist, to ensure that data is useful and effective, both through the evaluation and adaptation of the data for local purposes. Therefore, greater investment should be made to share and retain experience and local knowledge within an organisation, as well as the provision of training by NRS, to allow local authorities to produce population statistics. This would empower local analysts to become more involved in the production of data where they could produce more bespoke statistics, as well as giving them the opportunity to evaluate not only the output of the estimates and projections produced by NRS but also the methodology and assumptions used to produce them.

7.8: CONCLUSION

This chapter has focused on the attitudes and experiences of local analysts who use population estimates and projections produced by NRS, and in some cases developed by their own organisations. Through interviews, focus groups and questionnaires, the findings in this chapter provide an insight into the use of demographic estimates and projections, including the accommodation of error beyond that which could be gathered from the exclusively empirical analysis presented in previous chapters. The issue of evaluation was an overriding theme of this chapter, with the importance of local knowledge emerging as a key finding. This chapter highlights the ways in which local analysts' familiarity and knowledge of local issues, demographic trends and geographical topography can help not only to identify potential inaccuracies and flawed assumptions, but also provide valuable information which may allow centralised agencies to tailor their practices to produce more effective population data in the future. Findings from this chapter suggest that local knowledge and relationships with the community not only play a role in the evaluation of these statistics, but also in communicating the results of these estimates and projections to planners and policy makers. By developing strategies based upon local knowledge and relationships, these results suggest that users can more effectively communicate the strengths and limitations of both estimates and projections.

These results clearly demonstrate that statistical models alone cannot fully evaluate population statistics as they fail to take into account the unique characteristics and quirks of an area, such as stranded Soviet fishermen or island transport links. It is therefore critical that when local, small area, population statistics are being evaluated, local expert knowledge is an essential tool, which should be used alongside traditional, empirical methods, in order to understand potential sources of error, as well as providing solutions to remedy any inaccuracies. While accounts given in this chapter suggest that funding and budget cuts have been impacting upon the ability of councils to engage with training and networking events; given the importance of involving local analysts in the development of small area population statistics, greater resources and funding is needed to invest in local demography. These resources could be used to provide training for those who wish to produce their own population statistics, as well as strengthening the links between centralised and local agencies.

Chapter 8: Discussion

8.1: INTRODUCTION

Overall, this project has explored accuracy relating to small area population estimates and projections in Scotland, both by measuring and modelling the level of error and bias, as well as engaging with users of these statistics, to examine how the concept of accuracy is understood in practice. This chapter reflects on the key findings from the analysis conducted in this thesis, with reference to the existing literature as discussed in Chapters 2 and 3. This reflection will assess the contribution this research makes to the existing body of literature regarding the practice of using small area population estimates and projections for informing policy making and planning decisions.

This chapter will be structured around the key findings from the analysis conducted in this thesis and will be split into five sections. In the first of these sections, the importance of the small area population statistics explored in this research will be discussed. This section will examine how valuable small area demographic data is to local users and how it is used. The second section in this chapter will focus on the comparison of estimation and projection methods, in particular examining how the Cohort Component method currently used in Scotland performs, with some results of this research suggesting that, for population estimates, alternative methods may be more appropriate. Following this comparison, section three will focus on the findings related to bias, particularly concerning population estimates, with emphasis on results which suggested a systematic under-estimate in the most deprived areas, highlighting an issue which could have damaging consequences for the most vulnerable communities. Section four will then examine the role of area characteristics more broadly, to examine the way in which the accuracy of both estimates and projections may vary across areas. The fifth and final section of this chapter will then consider all these key findings to weigh up the advantages and disadvantages of all the estimation and projections methods evaluated in this research. Using both an evaluation criteria developed by Swanson and Tayman (2012; 292-295) and the feedback given by local users as part of this project, the costs and benefits of each approach will be considered. In addition to this, future recommendations will be discussed, exploring the way in which the experiences from local analysts may help to improve the service currently provided and to increase the accuracy and usefulness of small area population statistics in the future.

8.2: THE IMPORTANCE OF POPULATION STATISTICS

Previous research has stressed the importance of population statistics in informing planning decisions in both the public and private sectors, as well as being used as denominators when producing rates such as employment or mortality rates (Marshall et al, 2017; Lunn et al, 1998; Rees et al, 2004). Engaging with users of population statistics as part of this research only emphasised the wide range of uses of population statistics, with participants spanning many different organisations, from local authorities to the NHS, as well as a range of departments within these organisations covering housing, education and the environment. Respondents in this research not only highlighted the many different ways in which both estimates and projections can be used but the level of detail and accuracy expected.

In the qualitative section of this research presented in Chapter 7, one of the primary findings was the extent to which participants were asked to provide highly detailed and accurate population statistics. Several participants detailed how population statistics had been used to inform planning decisions such as new water pipes and sewage works which required population figures for only a few hundred people, as well as highly detailed age specific projections for predicting school role sizes. While these participants acknowledged that it was not possible to provide data to this level of accuracy for such small areas, these findings highlight the demand for the kind of sub-council area population data which is the subject of this research, as well as the importance of evaluating the performance of estimates and projections for small areas. Although there are limitations in the capacity for both population statistics to provide reliable data beyond a certain level of detail, these findings demonstrate that there are many aspects of the planning and policy making process which are highly sensitive to small changes in the population size and age structure.

As well as finding evidence that small area population statistics are an invaluable tool in many aspects of public sector planning and policy making, it was also found that there was a great deal of reliance on centrally produced population data. In a majority of cases, participants responded that although they used population estimates and projections in their work, they did not produce their own, instead using the figures produced centrally from NRS. Even in cases where organisations did produce their own population statistics, the official NRS figures were used in some form, either to constrain their own figures or as a comparison. This widespread use of population statistics, and in particular the use of centrally produced estimates and projections, emphasises the importance of evaluating population statistics and in particular the Cohort Component methodology which is currently used by NRS.

8.3: EVALUATING THE COHORT COMPONENT METHOD

The first of the research questions defined in this thesis focused on the performance of the Cohort Component method and exploring whether this is the most appropriate method for producing population estimates and projections for small areas in Scotland. This section will therefore reflect upon the evaluation of this methods carried out as part of this thesis. Here, the Cohort Component method is compared with both the complex and simple alternative methods included in this analysis, in order to assess circumstances where the Cohort Component method is the most effective, as well evidence which suggests that there is a place for some of these alternative methods in Scotland.

8.3.1: Comparing Complex Methods

In order to evaluate the Cohort Component method fully, alternative estimation methods such as the Ratio Change method used by the Office of National Statistics (ONS) in England and Wales and the Average method, used by the Northern Irish Statistical Agency (NISRA) were compared. The aim of including these methods in this study is to examine, whether the Cohort Component method is the most suitable method for producing small area population estimates in Scotland, compared to methods favoured by other statistical agencies.

When comparing the performance of these methods, results from the multilevel model analysis revealed that, on average, both the Ratio Change and Average estimation methods performed better than the Cohort Component method. For the total population, it was found that all of the methods favoured by UK statistical agencies performed more similarly to one another than the simpler methods.

Firstly, looking at the performance of the Average method, previous analysis has shown some evidence to suggest that averaging the results of two or more estimation methods produces more accurate estimates compared to using a single method. Research by Hoque (2012) found using an average of three methods resulted in estimates with a lower level of error compared to those produced using a single method, with Hoque (2012:99) suggesting that, "*using an average of three methods is superior to the use of any single method of estimation*" when comparing estimates to the census population, as applied in this research. Hoque (2012) also produced population estimates using two methods. It was found that when averaging the estimates produced using a version of the Cohort Component and Housing Unit method, the result produced a more accurate estimate than each of these methods individually. Hoque (2012) found that in nearly all cases, regardless of issues such as population size, the average method outperformed the individual methods. While there are some differences between this research and that carried out by Hoque (2012), namely the size of the areas studied and the methods chosen, these findings go some way to support the findings presented in this thesis, which suggests that averaging estimation methods can produce more accurate results compared to choosing a single method.

While some of the results from this study support those from previous research, other findings were not in line with the existing literature. One previous study which has compared these methods for producing small area population estimates was conducted by Lunn et al (1998). In one of the most comprehensive research projects exploring the accuracy of small area population estimates in Britain, the 'Estimating with Confidence' project compared a range of estimation techniques including indicator methods such as the Ratio Change and Apportionment methods as well as the Cohort Component or Cohort Survival methods. In this research, Lunn et al (1998) produced a range of small area population estimates for 1991 and evaluated their accuracy. Some of the methods included in the study Lunn et al (1998) were the same as those tested in this current research. Overall, results of this analysis found that, the Cohort Survival method, which followed the same process as the Cohort Component method used in the current study, was the most accurate of these estimation methods, while the methods which used symptomatic indicators of the population, such as the Ratio Change and Apportionment methods were less accurate.

While these results appear to contradict the findings from the analysis in this current study, there are some ways in which the results of this thesis builds upon the work of Lunn et al (1998). When reflecting on their Estimating with Confidence project, one issue which Simpson et al (1997) discuss is the potential for advances in data availability that could improve the accuracy of methods which use indicators of the population size. They suggest that, *“A fourth and major influence on estimation methods is likely to be a newly accessible dataset. Lists of general practitioners’ patients held by each Health Authority in England and Wales and by Health Boards in Scotland, have been computerised such that they will be accessible for statistical research by government. They are attractive because they aim to cover the whole population for all ages, and they record data of birth sex as well as unit postcode; their accuracy is thought to be increasing as general practitioners’ services are closely monitored by health authorities, and may be less affected by social and political trends which led to lower electoral registration in the 1990s”* (Simpson et al, 1997:279). While the results of this research by Lunn et al (1998) found that the Cohort Survival method produced more accurate estimates, they suggest that there are some limitations to this comparison, including the quality of the data which was used to produce the Ratio Change and Apportionment estimates. In the Estimating with Confidence project, the Ratio Change and Apportionment methods used the electoral roll as the indicator of the population, which Simpson et al (1997) acknowledge may not be a reliable indicator, particularly during the 1990s. They suggest that in the future new patient register data will be available which could improve the quality of indicator based estimation methods. As a result of advances in the digitisation of patient registers and laws surrounding Freedom of Information Requests, this data has become more readily available and was the source used as an indicator of the population when producing Ratio Change estimates in this current research project. Simpson et al (1997) predicted that, should this data become available, the potential for their use in producing population estimates would be ‘enormous’. Since this project was conducted in the 1990s, these predictions by Simpson et all (1997) have come, at least in part, to fruition, allowing this current research to build upon the evaluations carried out in the ‘Estimating with Confidence’ project.

Overall, when comparing estimation methods favoured by other UK statistical agencies to the Cohort Component method used in Scotland, it was found that these alternative methods outperformed the Cohort Component method, both for the total population and when broken down by age. Later in this chapter, the factors which may influence estimation and projection accuracy will be discussed, which may go some way to explain why these differences in accuracy may have occurred, as well as exploring whether, some methods may be more appropriate for some areas compared to others.

8.3.2: Performance of Simple Methods

The Cohort Component method is a widely used and popular method in the production of both population estimates and projections, with Burch (2018:135) describing the approach as "*the standard method, sanctioned by academic demography, national governments and by influential international organisations such as the United Nations and the World Bank"*, however, for smaller areas of geography like those which are the subject of this research, it can be more difficult to acquire the data necessary to apply this method. For this reason, alternative population estimates and projections were produced using simpler methods which can be produced using population counts from census or population estimate data.

8.3.2 a) Simple Estimation Methods

Overall, results from the analysis of both the population estimates and projections found that in the regression analysis in Chapters 5 and 6, that the simpler methods did not appear to outperform the Cohort Component method. Initially, when looking at the analysis in Chapter 5, it was found that the simpler estimation methods, i.e. the No Change, Shift Share and Constant Share methods, were less accurate than the Cohort Component method and other complex methods which were also included in the analysis. When evaluating the estimation methods, the No Change approach can be used as a benchmark of accuracy, indicating the margin of error which could be expected if no annual estimates were produced and it was assumed that the population remained consistent between censuses. Results from the analysis show that the No Change method outperformed or performed as well as both of the simple methods included in this study. When looking at average error, it was found that the population estimates produced using the simpler methods had substantially higher levels of error compared to the more complex methods. Across all age groups, there was around a 10% difference in average error between the simple and complex methods, with the simpler methods being consistently less accurate compared to the complex methods. When comparing the levels of error produced by each method further, using multilevel modelling, it was found that the Constant Share method produced higher levels of error compared to the No Change method, while the level of error present in the estimates produced using the Shift Share method was on par with the error present in the No Change estimates. These findings suggest that, for sub-council areas in Scotland, these simpler methods are no better for understanding the current population size than using the previous census and assuming that the population has remained static in the preceding years.

While these findings suggest that the complex methods outperform the simpler methods, there were cases where, for specific age groups within some data zones, the error for estimates produced using the simpler methods was lower than those produced by the Cohort Component Method. In around 30% of the age specific estimates, simpler methods produced population estimates which were more accurate than those produced using the Cohort Component method. Areas where simple methods outperformed the Cohort Component method did tend to share common features, namely the presence of special population groups. For example, data zones in both Craiglockhart and Lossiemouth, the simple methods produced more accurate estimates compared to the Cohort Component method. Both these data zones were highlighted in the NRS' (2013) Reconciliation report as areas where the estimates had a substantial error. In this report, Craiglockart was discussed as an area which has undergone some substantial changes in the population of 17-24 year olds as a result of the closure of student accommodation close to Napier University between 2001 and 2011; while in Lossiemouth, error was attributed to the misallocation of the armed forces population in the neighbouring data zone to that intended. These findings suggest that in some cases, the approach taken for processing special populations, such as the armed forces, students or prisoners, by Cohort Component method may, in some cases, result in higher levels of error. When looking at the cases where there were substantially higher levels for error found for the Cohort Component method compared to the simpler methods, findings from the NRS Reconciliation report suggest that changes or assumptions made concerning special populations, influenced the accuracy of the Cohort Component estimates.

In some cases, it can be easy to see how rapid changes in infrastructure or lack of understanding of a local area can result in a large disparity between the estimated and observed populations. As special populations are processed as large groups who change and age as a block, when errors are made or substantial changes happen, the error or mistake will affect a whole group rather than only some individuals within the total population. This is particularly an issue for the small area estimates and projections studied in this research. Rayer and Smith (2010:148) explain that *"Although changes in special populations affect growth trends for states and counties, they are of greater concern at the sub-county level because they typically account for a much larger proportion of the total population*" and "*Special populations can present a challenge to population forecasters because they often have unique demographic characteristics and may follow different growth trajectories than the rest of the population*". Rayer and Smith (2010) also explain that while it was important that special populations were accounted for separately due to differences in population growth and ageing, compared to the rest of the population, they also suggest that this treatment of special populations such as university students, prisoners and armed forces personnel, should only be used when they constitute a 'substantial proportion' of the total population and where the growth of this population 'differs markedly' from the rest of the population. However, Rayer and Smith (2010) further explain, that these definitions of when special populations should be processed separately, are vague and undefined, with no official definition of a 'substantial proportion' or 'markedly different growth'. It is therefore the responsibility of the analyst producing the estimate or projection to decide whether it is necessary to process these special groups separately from the rest of the population. While their analysis concluded that the separate processing of special populations is 'generally advisable' and was found to improve accuracy, Rayer and Smith (2010) recommend that this approach is best taken when there is 'good information' regarding the future of these special populations. The conclusions from this study validate the approach taken by NRS and other statistical agencies which process special populations separately, however the issues discussed previously in this chapter suggest that there are cases where the source of information around these special populations may not be reliable.

While in the minority, there were several areas where it was found that the Constant Share, Shift Share and No Change methods produced more accurate population estimates than the Cohort Component method. However, it could be argued that, rather than these methods performing particularly well, the data zones where the simple methods out-performed the Cohort Component method were areas which were particularly difficult to estimate, with the examples of Craiglockart and Lossiemouth discussed above highlighting some on the issues which can impact upon the accuracy of the Cohort Component approach. This issue of how some area types may be more difficult to estimate and the role of area characteristics cited by Marshall et al (2017) will be explored later in this chapter.

Although these findings may suggest that the more complex methods and even the No Change method outperform these simple methods when producing sub-council area population estimates, it is important to acknowledge that these results should not be extrapolated, and may not be found in other geographies or time periods. This is particularly important to consider when evaluating the Shift Share method. The Shift Share approach is intended to be more sophisticated than the Constant Share method as it uses population data from two census years in order to take into account the historical changes in the population share, with this research using the 1991 and 2001 censuses. It is this use of the 1991 census in particular which may limit the accuracy of the estimates produced using the Shift Share method as there have been suggestions that the data collected was particularly unreliable and incomplete. While the census response rate is never likely to achieve a 100% coverage, the 1991 census has been highlighted as a case where there was a significant number of non-responses (Mitchell et al, 2002), with Simpson and Dorling (1994) estimating the deficit to be around 1.2 million people across the UK, equivalent to 2% of the population. One of the most common explanations used to explain the high number of individuals missing from this census was the role of the Poll Tax and non-payment protest. While Simpson and Dorling (1994) suggest that the influence of the Poll Tax is limited, the issue of the Poll Tax may be particularly powerful in Scotland. Previous research by Barker (1992) into the opposition to the Poll Tax, found that non-payment played a more significant role in the opposition to the tax in Scotland, compared to elsewhere in the UK, with a higher proportion of the population being legally pursued for payments compared to England and Wales. This suggests the 1991 census in Scotland may be particularly unreliable and its use in this research to produce population estimates using the Shift Share method could be seen as a limitation of this research. It may be possible, that should this research be reproduced in the future, using different, more reliable censuses, results may differ from the findings of this study.

8.3.2 b) Simple Projection Methods

As with the analysis of the population estimates, it was also found that simpler projection methods produced less accurate results compared to the Cohort

Component method. Overall, results from Chapter 6 found that the Cohort Component method was the best performing projection method, with the regression models indicating that the Arithmetic, Exponential and Geometric methods all produced higher levels of error throughout the projection period. As well as the Cohort Component method proving the most accurate of these methods, it was also found to be the most consistent over time, suggesting it would be the most effective for producing long-term projections, beyond the five and eight periods examined in this research.

While the results presented in this thesis demonstrate that the Cohort Component method was the most accurate method over the course of the projection, the evaluation of the simpler methods could suggest that these methods may also produce satisfactory projections over a short projection period. Although the Cohort Component method consistently outperformed these simple methods, when examining the performance of each method in the context of 'shelf-life' as defined by Simpson et al (2018), the simple methods were found to produce reliable estimates for at least a five-year projection for both total and age specific projections. Overall when comparing projections produced by the Cohort Component and simpler methods, there were modest differences in accuracy of projections used by each method, suggesting that while the Cohort Component method may produce the most accurate projection, over a short period, the difference between methods is marginal.

These findings are somewhat consistent with analysis conducted in previous research and it could be argued that the results from this analysis add support to the findings of other research in this area. One of the main findings from this research was that, on average, there was little difference in the performance of each of the projection methods included in this study. The Geometric and Exponential methods performed the most similarly, with these methods producing the same projected population figures for a majority of areas. Smith et al (2014:208) explains that these results would be expected as *"When they* [population projections] *have the same base year and launch year, projections for areas with slow or moderate growth rates often fall within a fairly narrow range".*

While it may be expected that the Cohort Component method would be consistently the best, these findings that, in some cases simpler methods could perform just as well as the Cohort Component method are supported to some extent by previous research. As discussed in Chapter 3 when differentiating between simple and complex methods, Smith (1997) states that there is no standard definition used to distinguish between these types of methods, but that there is an apparent consensus whereby Cohort Component methods are seen as complex, and linear and extrapolation methods as simple. These definitions fit with the classification of the methods used in this research with the Cohort Component method regarded as complex and the mathematical methods regarded as simple, allowing a comparison to other research which has evaluated simple and complex methods. Rayer (2008:423) explains that *"there have been numerous studies (Ascher 1978; Isserman 1977; Long 1995; Murdock et al. 1984; Smith and Sincich 1992; Stoto 1983) which have demonstrated that complex models are no more accurate than trend extrapolation techniques for total populations".* While these previous studies have primarily focused on population projections for large areas such as nations or US states, Rayer (2008) found that these findings can be applied to all levels of geography. In a comparison of projection methods for US counties, Rayer (2008) found that, for short term projections produced using simple trend based techniques, results were comparable to projections produced using the Cohort Component method. In what Smith et al (2014) describe as one of the most comprehensive studies of this type conducted by Smith and Sincich (1992), similar results were found, with simpler methods, including the Arithmetic and Exponential methods, proving to be neither more nor less accurate than more complex or sophisticated approaches when tested over a range of projection lengths. While it is emphasised that these results should be treated with caution, Smith and Sincich (1992:507) state that they *“Have demonstrated that for a large number of projections covering different launch years and horizons, complex techniques did not produce more accurate forecasts of total population than simple techniques and sophisticated techniques did not provide more accurate forecasts than naive techniques. Although there are many reasons why complex or sophisticated techniques may be more useful than simple, naive techniques, the evidence to date clearly suggests that greater forecast accuracy is not one of them”.*

These findings from previous research support the results from the current analysis and comparison of simple and complex projection methods, and suggest that they contribute to a growing and substantial body of evidence that simple techniques can perform as well as complex methods, in certain circumstances. As with the previous pieces of research cited, results from this research must be caveated. Like past research, this project is limited in its scope, in terms of level of geography, projection length and range of methods. While this study compares simple to complex methods, there are only a limited number of projection techniques included in this analysis tested over relatively short projection periods. Any future research may be expanded to include additional methods such as ratio methods, for example the Constant Share and Shift Share methods, to more fully assess and compare the available methods for producing population projections.

The ease in which these simpler methods can be produced has the potential to empower local analysts to create their own projections, referred to by Ahlburg et al (1998:197) as the *“democratisation of population forecasts”.* Ahlburg et al (1998), describe how this empowerment may result in population projections being produced for new small areas which central agencies have not covered before, as well as providing local users with the ability to challenge established agencies. However, they also warn of dangers associated with local users producing their own projections. One of the main concerns cited by Ahlburg et al (1998:197) is the problem of having multiple projections existing at once with potentially competing results, describing how *“users may get confused if there are too many forecasts floating around and if they have no means to judge whether a forecast is based on a serious research effort or just a careless calculation”*. This issue of multiple projections ‘floating around’ was a concern which was also directly raised by participants who took part in the interviews and questionnaires discussed in the previous chapter (chapter 7). Some participants who worked in organisations which already produced their own population estimates and projections explained how multiple projections could cause confusion. This confusion reduces the usefulness of population projections as users must judge which of the projections are more reliable or are likely to be more accurate. As well as multiple projections having the potential to cause confusion amongst users, locally produced projections may also be more likely to be produced using biased assumption. While local knowledge in the creation of population statistics can be seen as being advantageous, as analysts on the ground have greater knowledge of ongoing projections and local trends, it is also possible that, in some cases, local analysts have a more vested interest in producing population data which shows a particular outcome which justifies or supports policy decisions. While central agencies may lack the local knowledge that could increase the accuracy of population estimates and projections, to some extent, this could be an advantage as this would make them more impartial and free from political influence in ways that local users may not. While local agencies may manipulate results to influence policy decisions, central agencies such as the NRS would be unaware of local issues and free from the influence of planners and policy makers.

Overall, examining the results of this research, along with findings from previous studies, there is a suggestion that there cannot be a firm conclusion made as to whether complex methods provide more accurate and reliable population statistics compared to simpler methods. While the results from the population estimate analysis appear to be conclusive, with each of the simple methods appearing to be no better than assuming no change in the population from the previous census, there was a more mixed picture when comparing population projection methods where complex and simple methods performed more similarly to one another. Before advocating for any particular method, the features of each estimation and projection method must be discussed further.

8.4: BIAS

As well as evaluating population estimation and projection methods based upon level of absolute error, methods were also evaluated based upon bias. Bias refers to the direction of error present in population estimates and projections and whether they are over or under estimated and is seen as an alternative measure of accuracy. This bias was calculated using the percentage error with negative values indicating that the estimate or projection was too low and positive values too high. Understanding the bias present in population statistics is important as it can provide users with more practical information into the uncertainty present in population estimates and projections as well as a greater insight into how errors can be corrected. While using an absolute measure of error can help individuals who produce population estimates and projections to compare the performance of methods, focusing on bias and the direction of error helps users of population statistics to better interpret the data. As these statistics can be used to allocate funding and resources, having knowledge of any bias is important for users as this could result in some areas being under funded if under estimated, while resources may be wasted if populations are over estimated. In this research, this issue of bias was explored, with analysis examining how bias differed between different types of areas, as well as how bias changed across the projection period. In this evaluation, only the best performing estimation methods, namely the Cohort Component, Ratio Change and Average methods were included. As the simpler methods performed on par with assuming No Change between census years, it was assumed that it was unlikely that any of these methods would be adopted by NRS to replace their current methodology.

8.4.1: Bias and Deprivation

One of the most striking areas where bias was found in population estimates was in relation to area deprivation. Analysis presented in Chapter 5 showed that a relationship existed between area deprivation and error bias, with the most deprived areas more likely to be under-estimated and the least deprived areas over-estimated. This appeared to be a consistent finding with a clear divide between the five most deprived deciles where more data zones were under-estimated than over estimated, while in the five least deprived areas the opposite was true. While this clear divide was most apparent in estimates produced using the Cohort Component method, there was evidence to suggest that this relationship between area deprivation and error bias existed across all methods included in this analysis.

These findings are significant and could have potential negative consequences for policy makers who are trying to tackle inequality. As population estimates are used by government agencies and local authorities to allocate funding and resources, the findings from this analysis suggest that patterns of error bias found in population estimates related to area deprivation, may mean that resources are being misallocated. As the populations of affluent areas were more likely to be over-estimated it would result in these areas receiving more funding and resources than needed, while the under-estimation bias found in deprived areas means that these areas are receiving less than they need. This bias, therefore not only has the potential to undermine efforts to tackle inequalities, but is also reinforcing inequalities by maintaining disparities in assets and wealth. As well as having an impact upon resource allocation, the error bias found in this research also has the potential to impact upon secondary statistics which are calculated using population estimates as a denominator. Rees et al (2004) describe how population estimates are used in the production of a wide range of statistics, particularly those presented as rates, such as death rates, employment rates or used to calculate Standardised Mortality Ratios or life expectancy data. As these statistics have a wide variety of important uses, such as acting as an indicator of a population's health and wellbeing, used as evidence in academic research and employed in policy making and planning, it is important that they are as accurate and reliable as possible. The findings from this study, could therefore have knock on consequences for the accuracy of these secondary statistics. As these statistics which can act as an indicator of deprivation, including when producing the SIMD, are calculated using population estimates, errors and bias could further reinforce inequalities or mask social problems as a result of the errors in these population estimates.

8.4.1 a) Deprived Areas and Demographics

One reason why this bias may exist may be that areas which are more deprived are generally more difficult to estimate. As will be explored later in this chapter, findings from this research suggest that there are some area characteristics and demographic groups which are estimated less accurately compared to others. It could be argued that these demographic groups, which are more difficult to capture in population estimates, are more likely to live in more deprived areas, resulting in an under-estimation bias. When examining previous research which has explored the demographic composition of areas of deprivation, there may be some evidence to support this theory.

One of demographic factors which was found to have a negative influence on accuracy for population estimates was ethnicity. This may be relevant in explaining the observed bias in deprived areas as research carried out by GOV.UK (2018) found that, in England and Wales, individuals from ethnic minorities were more likely than White British individuals to live in areas of deprivation. While these findings suggest that there may be some link between ethnicity and deprivation which could explain some of the findings from this study, when looking at the data from Scotland, the picture is more complicated. In analysis carried out by the Scottish Government (2014), it was found that, while the relationship between ethnicity and deprivation may not mirror that found in England and Wales, there is some evidence from the analysis of the 2011 census that certain ethnic minority groups, African, Black Caribbean and Other ethnic groups are over-represented in deprived areas while white British, white Irish and White other groups are under-represented. Further research also supports this with the Poverty and Inequality Commission (2017) stating that 35% of Minority Ethnic people are living in poverty compared to 18% White British people in Scotland. This suggests that, to some extent the relationship between deprivation and ethnicity may contribute to some of the bias in error observed in this current research, however, as the link between ethnicity and deprivation appears to be less pronounced in Scotland than in other countries (Poverty and Inequality Commission, 2017; Gov.UK, 2018), the impact may be limited.

8.4.1 b) Impact of Census Undercount

As this bias was present for all methods, it suggests that this trend is not unique to the Cohort Component method and would still occur if an alternative method was adopted to produce Scotland's small area population estimates. One reason why populations in more deprived areas are more likely to be under-estimated for all methods may be a result of an error in the census, which is used as the base population for all methods. Any census undercount may contribute to the relationship between estimation error and area deprivation which was observed in this research, with previous research finding that response rates are lower in deprived areas (Rahman & Goldring, 2006). In previous research which has used statistical modelling techniques to explore which areas are 'hard to count' in the census, areas with high levels of deprivation have consistently been found to be an indicator of census under-numeration. In research conducted by NRS (2015) it was found that area deprivation played a role in the population undercount, particularly in difficult to count, urban areas. This finding was supported by similar research carried out by Martin (2010) in England and Wales following the 2001 census. In this research, Martin (2010:2767) describes how areas which were observed to have a 'substantial undercount' and areas where there were more households recorded than expected both occurred at the "*extremes of the government's indices of deprivation"*. These findings fit with results of this research where the 10% most deprived areas, were the most likely to be under estimated, with 40% of data zones in this decile under-estimated.

While there is some evidence from previous research to suggest that differences in census response rates may influence error bias relating to area deprivation, it is unlikely to be the sole factor responsible for this trend. Should base population error be the only cause of this bias, it would be expected to be the same across all methods. Despite this bias being observed across all methods, it was more evident for some compared to others. Overall, it was found that the relationship between error bias and deprivation was strongest for the Cohort Component method, followed by the Average method, with the bias less evident for the Ratio Change method. This suggests that there are more factors responsible than any error inherent in the base population of each method, such as the demographic factors discussed previously.

8.4.1 c) Countering Deprivation Based Estimate Bias

As this relationship between error bias and area deprivation was found to some extent for all of the methods evaluated in this study, it would suggest that simply adopting a new method would not be enough to overcome any problems associated with this bias. This means that instead of changing methodology, the issue should be highlighted in documentation attached to the official release of the small area population estimates, with users informed that data zones in the most deprived areas may be under-estimated. There currently appears to be some recognition of this problem, as in the documentation for the adjusted population estimates which were revised by NRS following the release of the 2011 census, it states that the data zones in the most deprived deciles underwent the greatest revision, "*Estimates for the most deprived areas (Scottish Index of Multiple Deprivation (SIMD) 2012 deciles 1 to 7) in Scotland were revised upwards, with the estimates in the least deprived areas (SIMD 2012 deciles 8 to 10) being revised downwards"* (NRS, 2014:4). While this demonstrates that there is some awareness of this problem, this revision and subsequent explanation takes place as the estimates are revised during a post-hoc analysis. As population estimates are designed as a snap-shot of the current population size, providing caveats after the fact may be of limited use to users. In the future, the analysis conducted in this study may be extended to evaluate the bias present in population estimates over multiple time periods. Should it be the case that this relationship between bias and deprivation is found for multiple years, it could be argued that NRS could include additional information along with the methodology papers and technical notes which are currently provided to highlight this bias to users, planners and policy makers.

8.4.2: Deprivation Based Bias and Population Projections

Although there was a statistically significant relationship found between error bias and area deprivation for population estimates, an interesting finding from this research was that no such relationship was found for population projections. When comparing the target year of 2011 for the five-year projection to the 2011 census, no significant relationship was found between the direction of error present in the population projections and area deprivation. While this analysis tried to emulate the process used in that conducted for the population estimates, there were some differences which could be seen as limitations of this. As the population projections are produced for SCAP areas which are typically multimember wards or geographies of an equivalent size rather than data zones which are used for population estimates, the SIMD could not be used directly as an indicator of deprivation. Instead, an average SIMD score was used, using the SIMD rank of each data zone in a SCAP area which were then organised into deciles which were used in the analysis. By using this average SIMD score rather than the SIMD data directly, the reliability of these results may be limited. In the future, a different measure of deprivation, calculated specifically for these geographies may be used, in order to explore the effects of area deprivation on the ‘accuracy’ of population projections more comprehensively.

8.4.3: Bias Over the Projection Period

One area where there was some evidence of bias in population projections, was found when examining how the direction of error changed over the projection period. When tracking the error over the length of the projection, and observing how the error changes over time, it was found that for all methods, over 99% of projections in the first year were classed as ‘accurate’, with the error falling within 5% of the census population, with this proportion decreasing over time. As the proportion of ‘accurately’ projected areas decreased over the projection period, for all methods, areas were more likely to be under-counted than over-counted. While throughout the projection, the level of ‘accuracy’ remained high across all years, with the lowest level of ‘accuracy’ sitting at between 80% and 82% in the final year of the five-year projection in 2011 for all methods; when error did occur, more areas were under-counted than over-counted. Even when extending the projection period to 2014 the same results were found. This trend was most evident for the Arithmetic method, with the largest difference between the proportion of areas over and under counted.

These findings are supported by previous analysis conducted by Smith (1987) who also found that population projections tended to demonstrate a ‘downward bias’. Smith (1987) also found that this bias was correlated with population size, with areas with small populations more likely to be undercounted than areas with larger populations. This finding is particularly relevant to this current research which focuses on small area population projections. In Smith’s (1987) research, it was found that in areas with a population over 100,000, projections were more likely to produce an upward bias, while in areas with smaller populations there was a downward bias. As the populations of areas studied in this research are substantially less than 100,000, with an average population of 17,766 in 2011, the results of this research, that an undercount bias is likely to emerge throughout the projection period, would be expected based upon previous findings by Smith (1987).

Overall, when exploring the issue of bias in population estimates and projections, some mixed results were found. Results of this analysis strongly suggest that there are significant biases found in population estimates for all methods, with the most striking results observed in areas of deprivation which were consistently more likely to be under-estimated and affluent areas over-estimated. This is an issue which should be explored more in the future, as it has the potential to result in widening levels of inequality should planners and policy makers fail to take this bias into account. While bias was found to be a significant factor in population estimates, for projections, there was little evidence of a relationship between area types and bias. When exploring the issue of bias in population projections further, it was found that the bias present in the projections changed over time with the proportion of accurate areas decreasing, and areas with higher levels of error more likely to be under-counted than over-counted. This suggests that the length of the projections period may have a more significant role in affecting the accuracy of population projections than area characteristics. To explore this in greater detail, the role of area characteristics and population demographics on the accuracy of population estimates and projections will be discussed in detail in the next section of this chapter.

8.5: AREA CHARACTERISTICS

As well as exploring how bias in population statistics differed between area types, the relationship between area characteristics/composition, and error was also studied. Examining the effect which the demographics of an area can have on the accuracy of population estimates and projections is important, as it can help in understanding the factors which contribute to the inaccuracy present in population statistics, beyond the natural margin of error, which is inevitable when using any estimation or trend based projection. There will always be some level of imprecision in these statistics, as they are somewhat speculative and reliant on assumptions and expectations. However, the findings previously discussed in this chapter that the levels of error were higher in some areas compared to others, suggest that the demographics or characteristics of the population of particular areas do have some influence on the accuracy of small area population statistics. There is some evidence from previous research (Marshall, et al, 2017; Lunn et al ,1998) that area characteristics, such as rates of migration and unemployment, impact upon the performance of small area population estimates in England and Wales, for this reason a range of area characteristics were included in the statistical analysis, to explore which demographic factors may influence error. In Chapter 2 of this thesis which reviewed the literature regarding spatial unevenness in population change, a number of demographic factors, such as age, class and ethnicity, were discussed in relation to their impact upon population growth and structure. This section will explore these groups in greater detail in relation to the results of the statistical analysis conducted as part of this research.

8.5.1 Multilevel Models

In this research, multilevel models were chosen as a way of comparing the influence of area characteristics on the accuracy of a range of population estimates and projections produced by a variety of methods. These multilevel models suggested area did have an important influence on error, explaining around a third of the variability in error in a variance components model.

8.5.2: Area Wide Variables

The first of the area characteristics which will be discussed are the variables which were concerned with the population as a whole rather than the demographic composition of the population within an area. These variables are population size and population change which took place in the area between the 2001 and 2011 censuses. In this analysis, it was found that for both population estimates and projections, population size negatively associated with error and population change positively associated with error, meaning that higher levels of error were associated with areas which have small populations/high rates of population change. This is likely due to areas with small populations being more prone to fluctuations in the population, for example seasonal workers or the building or demolition of housing. As a result, changes in the population have a greater impact for small areas, compared to larger geographies (Smith & Morrison, 2006).

8.5.3: Demographic Variables

As well as examining the way in which population size and change have an impact upon the accuracy of population statistics, variables relating to the characteristics of individuals within the population were also explored. When exploring the demographic variables which influence the accuracy of population estimates and projections, a number of factors were found to negatively impact upon accuracy.

When examining the area characteristics which had the greatest influence on accuracy, they differed for estimates and projections. For population estimates, it was found that ethnicity had the greatest impact upon error, with error increasing as the proportion of the population who did not identify as white, increased. However, this was not the case for population projections, where no relationship was found between projection “accuracy” and ethnicity. Instead, migration and the proportion of people who had moved to the UK in the last year, were found to have the greatest influence on error.

It was found that both for population estimates and projections, the demographic composition of an area did have an impact on accuracy, although these variables differed in the strength of their influence between estimates and projections, with results from the analysis in Chapter 6 suggesting that using area characteristics as an indicator of projection “error” is more difficult compared to estimate error. As discussed in Chapter 2, different social and demographic groups may share certain characteristics or behaviours which make them more difficult to capture in population statistics. This may mean that when members of a particular demographic, such as students or ethnic minority groups are concentrated in one particular area, it could have a significant impact upon the accuracy of population statistics.

Understanding that area characteristics, as well as population size and change, is important, as it helps to explain why the accuracy of population estimates differ across areas. By acknowledging these results, it may be possible for users of these statistics to take into account the potential for error, with users planning services in a primarily student area, aware that there may be a higher level of error present in the estimates they are using, compared to planners in areas with small student populations. As well as informing users, these results may also provide information regarding how error may change over time in response to changing demographics. An example of this would be the projected increase in the number of one person households in Scotland. In this model it was found that the proportion of these households had a negative impact on estimate accuracy. This could be a significant finding, as the number of one person households is not only the most common household type in Scotland but is also the fastest growing (NRS, 2017). This may mean that as the proportion of single occupancy households change over time, the accuracy of population estimates may decrease.

8.5.4: Age Structure and Error

As well as exploring the influence of area characteristics on error, how accuracy differed between age groups was also explored. Both the population estimates and projections studied in this project were age specific, meaning that the population was broken down into age bands. The importance of having population statistics by age was stressed by the users interviewed in Chapter 7, as planning for school places, social care facilities and other public services all rely on having reliable information regarding the age structure of the population. When examining the accuracy of population statistics for different age groups, it was found that, for both estimates and projections, some age groups were found to be more accurate than others.

For both estimates and projections, the 16-29 age group was found to produce the highest level of error while the most accurate figures were produced for the 45-64 age group. As previously discussed in Chapter 2, these findings could be attributed to differences in mobility and migration rates between age groups. The findings in this analysis, where the young adult age groups were found to increase the level of error in population statistics, correspond with previous research which found that these are the age groups which are most likely to engage in migratory behaviour (Tyrrell and Kraftl (2015). While these findings may be expected, they are important when understanding how error may differ between areas.

While the young adult age groups were found to have the highest level of error for both estimates and projections, when looking at the highest levels of error for population projections, it was found that the most extreme errors were found for the 0-15 age group in predominately student areas. For all projection methods, the Anderson and City area of Glasgow and St George/Harbour area of Aberdeen contained the most extreme errors, while the Cohort Component method also had high levels of error for the youngest age group in St Andrews in Fife. This is an interesting finding, as these three areas share some characteristics, in particular, a high number of students and a young age profile. These findings may suggest that when producing population projections, areas with younger populations, and especially student areas may prove more challenging when projecting fertility and birth rates. As previously discussed in Chapter 2 fertility rates can differ between different demographic groups, therefore, it could be argued that results from this research suggest that fertility rates in areas with large student populations are difficult to project into the future, impacting upon the accuracy of population projections. This is an issue which may be explored further in future research.

8.5.5: Intersectionality

Overall, the findings discussed in this section, as well as the results found regarding bias discussed previously, may be understood collectively using the theory of intersectionality. Rooted in black feminism, the concept of intersectionality was defined by Crenshaw (1989) and describes the way in which social categories such as race, class and gender are not isolated but are overlapping and interdependent systems (Oxford English Dictionary, 2019). While this theory is most commonly applied to individual identities, Hopkins (2019) explains that it is a concept commonly used in the field of social geography, although it is largely overlooked. Three areas are therefore identified by Hopkins (2019) where intersectionality is relevant and should be considered. These are in the areas of; ethnic residential segregation, transnational migration and finally embodiment and belonging. When reflecting on the issues discussed in Chapter 2 regarding theories which helped to explain spatial differences in population growth, these issues were explored, including the topics of residential segregation and the way in which group belonging (habitus) can impact upon behaviour. This suggests that intersectionality is an important point to consider when interpreting the results of this research, particularly when understanding the impact of area characteristics and error.

Results from this research, as well as the findings from previous studies (Marshall et al, 2017; Lunn et al, 1998), found that area characteristics did have an impact on the accuracy of population estimates, with several demographic factors found to impact upon the accuracy of both estimates and projections. In many cases is an overlap between the area characteristics and social groups which were found to be influential, such as population growth and the proportion of young adults, both resulting in higher levels of error. The intersection of social groups and its impact upon area characteristics is also evident in previous research. One example of this is in the research conducted by Bondi (1999) which was discussed in Chapter 2. This research found that young professional women were drawn to gentrified neighbourhoods of Edinburgh. This demonstrates how the intersection of social categories, in this case sex, class and age, rather than a single social identity influenced the character and demographics of an area. Therefore, while the analysis in this thesis examined the impact of demographic groups individually, it must be acknowledged that individuals can belong to more than one social category, with some categories more likely to overlap than others. Future research may explore this issue of intersectionality in more detail, examining the way in which social groups overlap and cluster in particular areas, and the potential impact on the accuracy of population statistics.

8.6: CHOOSING A METHOD AND RECOMMENDATIONS FOR THE FUTURE

Taking into account the findings from this research, which compared methods and explored the factors which influenced the accuracy of population statistics, along with comments made by the users of these statistics, it may be possible to recommend changes to the current practices used in Scotland regarding small area estimates and projections. While accuracy is an important factor when comparing estimation methods, Swanson and Tayman (2012) set out a number of criteria which they believe are also important when assessing the merits of particular methods, these are; Provision of necessary detail, Face validity and plausibility, Cost of production and timeliness and finally Ease of application and explanation. These criteria will be used to evaluate estimation and projection methods and assess the benefits and limitations of each of the methods examined in this research.

8.6.1: Choosing an Estimation Method

Firstly, when examining the estimation methods which were compared in this research, it was found that, overall, the Average and Ratio Change methods outperformed all other methods included in this study. This may suggest that one of these methods would be better suited to producing small area population estimates in Scotland rather than the Cohort Component method. To further assess whether either of these methods should be adopted in Scotland, they will be discussed in greater detail, exploring the qualities of these approaches beyond accuracy alone.

When assessing the merits of applying the Average method, it could be argued that this approach fails to meet several of the criteria put forward by Swanson & Tayman (2012), in particular, timeliness and ease of application. As the Average method involves two separate estimates, in this case the Ratio Change and Cohort Component methods, which both require different data, it could be argued that this method is overly labour and data intensive to be described as easy or to be applied in a timely manner. While this method is used by some statistical agencies, and average methods have been found to outperform single methods, as previously discussed, in departments and organisations which experience time and staffing pressures, the added accuracy found in Average population estimates may not outweigh the extra time and resources required to produce them. It is therefore difficult to justify the adoption of the Average method in Scotland despite the lower levels of error with which it is associated.

While the Average method could be seen as too time consuming to make it an appropriate method for producing Scotland's small area population estimates, the Ratio Change method was found to demonstrate a similar level of accuracy, without the added process. As well as being more accurate than the Cohort Component method, it was also found that the bias was less prominent for the Ratio Change method, with the bias slightly less pronounced, and with smaller differences between the observed and expected values compared to the other methods. Although these findings may suggest that the Ratio Change method would be a strong approach for producing small area population estimates in Scotland, there could be some challenges in accessing data which may mean that this method would not be consistently applied over time. As this method uses an indicator of population change to update the past population, administrative datasets must be used. In this research, the Community Health Index (CHI) was used as an indicator of the population, mirroring the methodology used by ONS. While this could be seen as a reliable source of data, administrative data such as this are vulnerable to change. Changes in how data is recorded, for example as a result of a policy change, may mean that this data source is no longer appropriate for producing population estimates. This has proved to be an issue in the past for ONS, when a policy change in 2013 which made child benefit means tested, based upon parent's income, meant that the child benefit dataset could no longer be used when producing population estimates (Park, 2017). Should policy changes require new sources of data to be used to produce population estimates, their usefulness may be reduced, as it makes it more challenging to compare estimates between years, as it would be difficult to measure the impact that a change in the data source had on, differences in the population size from year to year.

As well as issues in accessing reliable data to use as an indicator for the Ratio Change method, the use of administrative data may miss out certain demographic groups which could result in particular populations being missed in these estimates. As these administrative data sets are self-selecting, there is a reliance on individuals volunteering to engage with certain public services, with certain groups more reluctant to do this than others. In recent years, concern regarding the UK Government's "Hostile Environment" policy towards migrants has caused concern regarding how personal data is being used. There are currently concerns regarding the collecting of GP data and the sharing of this data with the Home Office as a method of identifying illegal immigrants, a practice which has been cited as deterring people from registering with health services (Sexton et al, 2017, Kmietowicz, 2018). This could lead to particular groups of people being excluded from population estimates. This not only highlights how vulnerable estimate methods, which use administrative datasets, are to changes in policy, but also raises ethical questions over how an individual's data should be stored and shared.

Overall, this analysis highlights some of the issues which could be associated with the Ratio Change method. While these estimates were found to be more accurate than the Cohort Component method, there is the potential for problems in finding appropriate and reliable data. Although this could be seen to be a limitation of this method, the fact that these issues have been overcome in the past by other agencies such as the ONS, demonstrates that it is possible to evolve the methodology and data, while maintaining quality. When considering the criteria set by Swanson and Tayman (2012), there are also some points where the Ratio Change method may outperform the Cohort Component method. On the issues of timeliness and ease of application, the Ratio Change process, which can use a single administrative dataset, could be seen as a simpler approach compared to the multiple datasets required for the Cohort Component method, particularly the datasets needed to measure migration. Despite the advantages of the Ratio Change method in terms of accuracy and data efficiency, this method could be seen as inferior to the Cohort Component method in terms of the level of detail. While the Cohort Component method requires a greater volume of data, it is this feature which gives analysts a more comprehensive insight into how the population has changed through natural change or migration patterns. By including each element of population change, the estimate can be deconstructed to reveal the processes which can explain the observed changes in the population. This is not possible when using only administrate data, as used for the Ratio Change method. Therefore, it could be argued that by adopting the Ratio Change methods in Scotland, population estimates would not only be more accurate but also easier to produce but may not provide the level of detail associated with the Cohort Component method.

8.6.2: Choosing A Projection Method

Using the same approach, it is also possible to assess the most appropriate projection method; in this section the complex Cohort Component method will be compared to the simpler mathematical methods. While the Cohort Component method outperformed the simpler methods overall, the projections produced by each of the methods were similar enough to one another for the simpler methods to be considered as a possible approach, particularly for local users.

In this research, it was found that, overall, the Cohort Component method outperformed the simpler methods in terms of accuracy, but also had many advantages over the alternative approaches included in this analysis. When again referencing the criteria developed by Swanson and Tayman (2012), they state that estimates and projections should provide a necessary level of detail. As discussed when evaluating the advantage of each estimation method, the level of detail which is provided in the output of projections produced using the Cohort Component method, is a clear advantage of this approach, as it provides details regarding changes in the drivers of population change. This level of detail is beneficial to analysts as it gives them a greater insight into how past policy or planning decisions have influenced both the extent to which the population has changed, but also how they have affected fertility, mortality and migration rates in their area. Taking into account this additional data, in conjunction with higher levels of accuracy, it could be argued that the Cohort Component method is superior to the alternative methods and is the most appropriate for use in Scotland. However, while this approach may appear the most appropriate for producing population projections on a large scale by a central agency such as NRS, when users are producing their own projections, the simpler methods may still have some value.

When discussing with users of these projections how they used the statistics and how they could be improved, one of the common points raised in Chapter 7, was the desire for local users to produce their own projections. Participants in this research explained that in many cases, projections were required for multiple geographical areas such as school catchment areas or housing areas. For this reason, it would be useful for these users to produce their own statistics rather than relying upon centrally produced data for a single defined area. When taking these comments into account, it is important to also evaluate each method within the context of being applied by non-expert users. While the aforementioned criteria of 'a necessary level of detail' is more closely associated with the Cohort Component method, the definition given by Swanson and Tayman (2012) for the 'provision of necessary details' also refers to the level of geographical detail, with population data needed for all geographical boundaries required by users. While it is possible to use the Cohort Component method for a range of geographies, the time and data required to produce a number of population projections in this way, could be seen as a potential limitation of this method. While there is a lack of demographic detail, for local authorities who wish to produce population projections that provide general population size and structure for broad age bands and a range of geographies; these simple methods provide an inexpensive and accessible way for local analysts to produce their own projections. Rayer (2008) supports the use of simpler methods, as trend based methods can produce a more neutral projection, free from potential biased assumptions which could influence the accuracy of the Cohort Component method. Overall, it is suggested that, regardless of the detail present in simple trend based projections, they can be a useful and valuable tool for comparison with more complex projections. Rayer (2008:427) explains that, "*At the very least, the trend projections provide an additional perspective, that is, population figures that can be compared with results obtained with other models. Trend extrapolations are easy enough to implement that the benefits of their use should outweigh any extra effort".*

As well as the level of geographical and demographic detail, many respondents of the questionnaire expressed their desire for long range projections. In order to evaluate each method fully, the performance of methods over time must be examined. The 'shelf life' of population projections has been defined by Simpson et al (2018) and refers to the reliability of projections over the projection period. This concept of 'shelf life' developed by Simpson et al (2018) describes the length of time which a projection can run while still being within a certain level of 'accuracy'. Based on this definition, it was found that for total and age specific population projections, all methods had a shelf life of at least five years, indicating that both the Cohort Component method and simple methods produce reliable projections over a five-year period, even with age detail. These results therefore suggest that simple methods could be seen as a reliable approach for some local users when producing short term projections, however when projections are needed over a longer time period, the Cohort Component method may be more reliable.

When evaluating which projection method is most appropriate for producing Scotland's small area population projections, this section considered the merits of each method, both in terms of 'accuracy' and how they meet the needs of users. Overall, based upon accuracy and level of detail, the Cohort Component method appears to be the best approach for producing population projections in Scotland. While the Cohort Component method does appear to be the most accurate, it could still be argued that there is still a role for the simple methods as a useful indicator of the population size and structure. Taking into account comments made by local users and the shelf life of these projections, simpler methods could be recommended to analysts in local authorities and other public sector organisations. Particularly, for those who wish to produce their own projections and lack the resources required to apply the Cohort Component method. These projections could fill any gaps in demand left by NRS, such as when projections are needed for multiple geographical areas.

8.6.3: Improving Output for Users

As well as evaluating each of the methods from a quantitative perspective, it is also important to evaluate how these statistics are currently used and how non-expert users and analysts can be empowered so that population statistics can be used more effectively. In this section, the feedback given by participants in Chapter 7 of this research will be discussed to assess if any recommendations could be made to improve how estimates and projections are used locally to inform planning and policy making more effectively.

One of the main issues which emerged from discussions with participants, was that non-expert users often found projections unrealistic or unbelievable. In the research, many respondents recounted their experiences of population projections being challenged by non-expert users, such as councillors or policy makers. While NRS currently use variant projections to provide a range of possible scenarios and provide context for projections, findings from this project and from previous research (Wilson and Rowe, 2011) found that these variant projections were limited in their usefulness and could result in more confusion. One way in which a particular participant found to make the figures more compelling, was to set the future projections in the context of how the population had changed in the past. By presenting expected changes in the future alongside changes which the audience had experienced in the past appeared to be a successful way of presenting projections in a more believable way. These findings suggest that including historical data as part of the projection output, may help users to understand projected population change within the wider context of how an area's population has evolved and changed over time. These findings also highlight how a model error, as produced for case study areas in Chapters 5 and 6, could help users understand both the potential for error in their area, and also how error may vary across areas. The results of the statistical models developed in this thesis could therefore assist local analysts when explaining the potential for error to lay-users.

As well as issues regarding the believability of estimates and projections, findings from this part of the research also found that respondents felt that local knowledge could be used more to improve the accuracy of these statistics. While local knowledge of future developments cannot be included in projections as this would change the data from a projection which continues past trends to a forecast which includes political assumptions, there could be a role in using local knowledge to improve assumptions in particular areas. One example of this was discussed earlier in this section with regards to the large error in the data zone housing RAF Lossiemouth, where the base personnel were allocated to the neighbouring data zone, while another would be the example given of the Soviet Klondikers in Ullapool who were there temporarily but would have impacted upon the base population, influencing the projection throughout the projection period. These findings suggest that, where possible, analysts from centralised agencies should consult closely with staff in local councils, such as at regular Population and Migration Statistics Committee Scotland (PAMS) meetings, to be made aware of any special populations or local policy changes which may impact upon the assumptions used to create the estimates and projections. In cases where local users wish to include future plans and policy changes in their projections, increased communication between central agencies and local users, could also be used to clarify the role of population projections as a tool which demonstrates what the future population would look like if past trends continued, rather than a prediction. This confusion over the purpose and limitations of population projections appeared in this research to be a problem for non-expert users which could lead to the projections being misused. By increasing the engagement between the producers and users of population projections, the expectations of planners and policy makers could be better managed, resulting in these projections being used more effectively.

8.7: CONCLUSION

Overall, this chapter has considered the merits and limitations of all of the projection and estimation methods evaluated in this study, taking into account their performance from a quantitative perspective, alongside the feedback given by users of these statistics. By using the criteria set out by Swanson and Tayman (2012) and Simpson et al's (2018) concept of shelf-life as a framework through which to evaluate each method, this chapter has assessed each estimation and projection method beyond a simple comparison of accuracy; focusing on the costs and merits of each approach. Through this more in-depth and considered analysis, it is possible to consider whether the simplicity, cost effectiveness and accuracy of the Ratio Change method out-weighs the benefits of the additional detail associated with the Cohort Component method. When evaluating projection methods, the results from this thesis, along with the findings from previous studies, also reveals some interesting findings which suggest that simple projection methods can be considered reliable in certain circumstances, over short periods, when the Cohort Component method cannot be used. This may give local users greater confidence when producing their own small area projections.

As well as aiding the interpretation of results, through this chapter, some results have been explored in greater detail in order to try and explain or develop solutions to issues raised in this research. In particular, the relationship between area deprivation and error bias was examined in greater detail. This chapter considered the issue of bias within the wider context, using findings of this current and existing research to discuss how demographic factors associated with higher levels of error, may be more common in areas of deprivation, resulting in the observed bias. This is an issue which was identified as an area which could be the subject of further research.

By discussing the results of this research in greater detail, there were also many areas where recommendations were made for the future, in particular in reference to improving the demographic statistics for local users and countering issues identified in this thesis. These recommendations included; making users more aware of the potential for bias in the methodology notes, fostering greater links and communication between centralised and local agencies and providing historical data alongside projections to provide context for future population change. These recommendations take into account the experiences and views of the respondents who participated in this research, based upon challenges which they had faced when working with small area population statistics.

Overall, discussing the results of this thesis alongside the findings from past research, has provided a greater context in which to interpret findings, identify areas where further research is needed and develop recommendations for the future. In order to assess how well these results have addressed the research questions set out in Chapter 4, the key findings of this thesis will be reviewed in the following chapter.

Chapter 9: Conclusion

9.1: INTRODUCTION

The purpose of this thesis was to evaluate the accuracy of population estimates and projections for small areas. As there has been no previous research of this type conducted in Scotland, the goal of this thesis was to make an important contribution to the existing body of knowledge regarding the performance of a range of estimation and projection methods in the Scottish context. By exploring the issue of accuracy in small area population statistics from both a quantitative and qualitative perspective, this project also aimed to provide a comprehensive evaluation of small area population statistics, both by attempting to explain the factors which may influence accuracy and by developing a greater understanding of the way in which these statistics are used and interpreted by local users. In this final chapter, the key contributions and findings from this research will be discussed, with reference to the research questions set out in Chapter 4. This thesis has produced many significant findings which make an important contribution to the existing body of research, both in an academic context and in its potential to have an impact beyond academia.

9.2: PERFORMANCE OF THE COHORT COMPONENT METHOD

The first research question defined in this research is; "*Does the Cohort Component method produce more accurate population estimates and projections for small areas in Scotland compared to alternative methods*". This section will reflect upon the performance of the Cohort Component method and the accuracy of this method compared to alternative approaches for producing small area population estimates and projections in Scotland.

9.2.1: Population Estimates

One of the key findings presented in Chapter 5 of this research, was the analysis which suggested that both the Average Method and Ratio Change method outperformed the Cohort Component method in terms of accuracy. Despite the Cohort Component method being a widely used and trusted method, results from this analysis suggest that this approach was less accurate than other methods included in this study. Results from the multilevel models conducted in Chapter 5 clearly demonstrated that all of the more complex methods, favoured by statistical agencies, outperformed the simpler, Constant Share, Shift Share and No Change methods. However, results from these models also revealed that the Ratio Change and Average methods produce lower levels of error, on average, compared to the Cohort Component method. As this Cohort Component method is the approach currently used to produce the official small area population estimates in Scotland, these findings, which suggest that other methods may produce more desirable results, could influence the current approach taken by NRS.

This comparison of methods used by other statistical agencies, is the first time each of these methods have been compared in terms of accuracy, addressing a gap in the literature which was identified in Chapter 3. There have been some studies in the past which have compared the estimates produced by the Cohort Component, Ratio Change and Average methods which found each method produced similar results, indicating that they were equally effective (Snowling, 2009; Dignan et al 2010) and justifying the approach taken by each statistical agency. However, there has been no previous research which has quantified the accuracy of these methods when compared to a 'population truth'. By comparing the estimates produced by each of these methods to the 'true population', this research found that, when producing small area estimates in Scotland, the Average method was the most accurate method on average, closely followed by the Ratio Change method. This analysis of the error produced by each of these methods provides a deeper understanding of the differences in the performance of these methods. In particular, the case study areas presented in Chapter, 5 showing the predicted error which would be expected in two specific data zones in Scotland, demonstrates the differences in accuracy between each method and gives an insight into the number of individuals who may be missing from the estimate produced by each method, rather than a more abstract percentage error.

These findings therefore, suggest that, not only is there a real and meaningful difference between these methods used by statistical agencies when comparing them in terms of accuracy, but also that both the Average and Ratio Change methods may produce more accurate population estimates for small areas in Scotland.

9.2.2: Population Projections

As well as evaluating the performance of a range of population estimation methods, this project also aimed to explore the accuracy of a range of population projections, comparing those produced using the Cohort Component method to more simple methods. The work carried out in this thesis to explore the performance of the Cohort Component method, used to produce small area population projections in Scotland, in itself makes an important contribution to what is known about the reliability of sub-council population projections in the country. With only a single experimental set of sub-council projections released in 2016, there has been little opportunity to evaluate these figures. In the analysis carried out in this research, the methodology used to produce these experimental projections was evaluated using historical data. The results of this research appear to suggest that the Cohort Component methodology produces high quality population projections, with this method outperforming the more simple methods examined in this research. When reflecting on the benchmarks of accuracy given in the feed-back from users, the range of error present in population projections produced using the Cohort Component method fell within the 10% error, which was the average response given by participants in this research when asked what level of error could be present in these population projections and continue to be useful. This suggests that the standard of the small area population projections produced using this method meets users' expectations.

When comparing projection methods, one key finding to emerge from this research, was that while the Cohort Component method produced the most accurate projection on average, the simple mathematical methods were, in some cases, of a sufficient standard that they may prove a useful tool for local analysts. Despite the projections produced using the Cohort Component method proving more reliable compared to the simple methods, results from the multi-level models used in this research suggested that these simpler methods were around 1% less accurate than the Cohort Component method. This small difference in error may provide local analysts with some confidence in these mathematical methods which are relatively simple and affordable.

When exploring how error changed over the projection period, it was also found that the accuracy of the Cohort Component method was the most consistent over time, with the error increasing more slowly compared to the simpler methods. However, when using Simpson et al's (2018) concept of shelf life to evaluate projection methods as used in Chapter 6, it was found that all methods evaluated in this study achieved the benchmark of being within 10% of accuracy in 80% of areas over a five-year period, for both total and age specific projections. This measure of reliability developed by Simpson et al (2018), aims to reflect the level of accuracy, whereby projections were considered useful and reliable to users. In this study, analysis revealed that all methods achieved a five-year shelf life, suggesting that over a short projection period, any of these methods could produce useful and reliable population projections, both for the population as a whole and when broken down by age.

Overall, these results provide a valuable insight into both the level of accuracy which may be expected from the experimental small area projections released by NRS in 2016, and how useful simpler methods may be for local users who seek to produce their own projections. When exploring the accuracy of the Cohort Component method, the results from the analysis in this thesis should provide NRS with some confidence, with this method providing projections which can be considered reliable and useful, based upon both the feedback from users and the concept of shelf-life as defined by Simpson et al (2018). On the whole, these findings that the Cohort Component method was the best performing overall, and provided the most consistently accurate projections over the course of the projection period, support the use of this approach for producing Scotland's sub-council area population projections. As well as supporting the use of the Cohort Component method, results from this analysis could also support the conclusion that the simple approaches examined in this research could be seen as a legitimate tool for local planners who seek to produce their own figures. With evidence from Chapter 7 suggesting that there was a desire from local users to produce their own population statistics, these findings which suggest that these simpler methods may provide reliable projections could have the potential to empower local analysts. While these simple methods may not provide as accurate or detailed data as the Cohort Component method, in some cases users may sacrifice some accuracy in order to produce their own figures at a low cost and with minimal resources. This research could provide these users with an idea of how accurate they could expect these simpler projections to be, compared to the Cohort Component method. Providing users with some knowledge of the degree of accuracy which could be expected from each of the methods explored in this research, as well as the factors which may increase error, local analysts could be empowered by this research, allowing them to produce their own estimates and projections as required.

9.3: AREA CHARACTERISTICS

The second of the research questions addressed in this research was concerned with the role of demographic factors, in particular place and age, impact upon the accuracy of population estimates and projections. With previous research, such as that discussed in Chapter 2, suggesting that particular area characteristics may impact upon the drivers of population change; this research question explores the way in which demographic factors may influence the accuracy of population estimates and projections which aim to capture these changes in the population. As this project focuses on the accuracy of population estimates and projections for small areas, even small changes in the population size could have a significant impact upon the accuracy of these statistics. As a result, it is important to attempt to explore some of the issues which were highlighted in the previous literature as influencing population change and to examine how they may impact upon the accuracy of small area population estimates and projections.

9.3.1: Demographic Factors and Error

When exploring the influence of area characteristics on the accuracy of population estimates and projections, results from the analysis in Chapters 5 and 6 suggested that the demographic composition of an area does have an effect on the accuracy of both small area population estimates and projections, to some extent. These findings go some way to explain why there is variation in the accuracy of these statistics between areas, with some places more accurately estimated or projected compared to others. Using the regression models in this research may help to identify areas for which it may be more difficult to produce reliable population figures.

An interesting result from this analysis also found that not only was there a relationship between demographic factors and accuracy, but that particular area characteristics influence the performance of each method in different ways, with interaction models used to explore differences between methods. This is an important finding as it may suggest that some methods may produce more accurate results in some areas compared to others. As previously discussed earlier in this chapter, there appears to be no one method which produces the most accurate population estimates or projections across all small areas. These findings help to explain why these differences may occur, with one method better suited to a particular type of area compared to another.

Taking these results into account, the models which were developed as part of this research may prove useful to both the NRS and local users to identify areas which may be more difficult to estimate or project to a great degree of accuracy. By recognising which areas may be more susceptible to error, more information may be included in the support documents provided with these statistical releases, to draw users attention to the potential for error. Results from this study may also provide local users with a useful tool through which they can calculate the potential for error in their area based upon its demographic profile. This could not only allow users to factor in error when using these population figures for decision making purposes, but also help to more effectively communicate the potential for error to less experienced users. As discussed in Chapter 7, some local analysts found it challenging to manage the expectations of non-expert users, such as councillors, when presenting population data. The results in this study have the potential to not only provide users with a greater degree of confidence regarding the expected accuracy of the figures, but may also give them more information to help explain why the expected level of error may occur in these areas, based upon increased knowledge of the factors which influence the accuracy of these population statistics. Using these models, local analysts who produce their own population statistics may also be able to identify which method would produce the most accurate estimates and projections based upon the demographics of their area.

9.3.2: Bias

One of the most significant findings contained within this thesis is the relationship between estimation bias and area deprivation. Results from analysis in Chapter 5 suggested a systematic under-estimation bias in the most deprived areas, with areas classed as the most deprived in the SIMD more likely to be under-estimated while the most affluent areas were more likely to be over-estimated. Evidence from this research suggested that, when using the Cohort Component method, around 40% of data zones in the 10% most deprived areas in Scotland are under-estimated, compared to 16.3% of the 10% least deprived areas. As well as the difference between these two extremes of the SIMD, when looking across the deprivation deciles, for the Cohort Component methos, there is as clear split between the five most deprived deciles where more data zones were under-estimated than over-estimated, and the five most affluent deciles where there were a greater proportion of data zones over-estimated than under-estimated.

These findings suggest a strong relationship between deprivation and estimation bias which occurs regardless of the method used to produce the estimates. This issue of bias exposes an important problem which could be having a damaging effect on the lives of communities which already require additional support. As these estimates are often used to allocate funding and resources based upon population size, this routine under-estimation of the population of deprived areas and over-estimation of the most affluent areas may mean that resources and funding are allocated unevenly. With the most affluent areas receiving more resources than required as a result of over-estimation bias, and the most deprived areas receiving less due to their populations being under-estimated, societal inequalities may not only be reinforced but exacerbated. The results from this research could provide those who produce population estimates with a greater understanding of the extent to which this bias exists, resulting in the development of strategies which could reduce or eliminate the bias present in these estimates, and help users allocate resources effectively.

9.4: UTILISING LOCAL KNOWLEDGE

The final research question which was addressed in this thesis, was concerned with the way in which local users interacted with small area population estimates and projections, and in particular, how they dealt with the uncertainty inherent in these statistics. When engaging with local users, one of the most striking themes which emerged was the extent to which the participants demonstrated that their own local knowledge of their areas helped identify potential errors present in these estimates and projections, and that their local knowledge could be used to improve the usefulness of these statistics. The key issues which were discussed in Chapter 7 will be discussed further in this section, exploring the ways in which this local knowledge could be utilised in the future.

9.4.1: Local Knowledge as an Evaluation Tool

When examining the responses from the questionnaire, conducted as part of this thesis, it was found that many of the participants used their local knowledge or a ‘sense check’ to assess how accurate they felt population estimates and projections were. This suggests that, even without a quantitative assessment of the level of error which may be expected from these small area statistics, local users do account for a certain margin of error when the data differs from trends which they observe in reality. This use of local knowledge reveals another way in which estimates and projections can be evaluated, and their usefulness assessed. As discussed previously, one of the aims of this research was to explore how users engaged with population statistics and accounted for error when using these figures. Results suggest that users interpret these estimates and projections critically, whether these statistics were produced in-house by the local analysts themselves or produced centrally by NRS. From this research, it was evident that users did not use these estimates or projections as certainties but reflected on changes in their local areas or quirks of their area which may have been missed in the methodology. While accuracy is an important issue to local users, these findings suggest that when substantial inaccuracies occur, they will likely be recognised by these local analysts.

9.4.2: Improving Estimates/Projections Through Local Knowledge

As well as recognising error, results from this research also found that local knowledge could improve the usefulness of the centrally produced statistics released by NRS. This issue was explored in response to comments made by Chi and Voss (2011), which were discussed in Chapter 2, suggesting that 'spatial population effects' may limit the accuracy of population estimates for small areas, in particular the physical restraints which may influence population growth. While Chi and Voss (2011) discussed the issue of 'spatial population effects' in relation to the accuracy of population statistics, in this research, these were issues explored from a different perspective, examining how the physical geography of an area and the resulting population distribution may impact upon the reliability or usefulness of the estimates or projections. Participants in this research discussed the way in which the population was distributed in reality was, at times, not effectively represented in the geographical boundaries created by centralised statistical agencies. Island communities were particularly affected by this issue, with the way in which some island populations were divided and combined, limiting the usefulness of population estimates and projections.

These findings suggest that accuracy is not the only measure of how effective population statistics are for informing planning or policy making decisions, but reveal that these statistics also need to be meaningful for those making the decisions. Should the geographical areas used in the statistics not reflect the physical geographies on the ground, these statistics may provide data which is of only limited use in practice. However, from the discussions with users conducted as part of this research, it is also clear that this is an issue which could be overcome by utilising local knowledge and increasing communication between central agencies and local analysts. Evidence from this research shows that this is already happening in some cases, with consultations between NRS and service users being held to ensure that the geographical areas used as SCAP areas in the 2016 experimental small area projections best suit the needs of users.

9.5: TRAINING AND FUNDING FOR LOCAL AUTHORITIES

While exploring the interaction between users and population statistics outlined in the third research question, it was also found that while local users wanted to produce more of their own population estimates and projections, and carry out more demographic analysis using these statistics, there were many barriers which prevented them from doing so. As one of the key results in this research was the finding that local knowledge is an important tool in the production of accurate, useful and meaningful population data, it is also vital that local authorities have the funding and resources required to continue to engage and collaborate with NRS, in order to produce effective and high quality population statistics for their small areas.

9.5.1: Training and Support Provision

As the results of this research reveal that there is some lack of confidence from local analysts when producing their own population statistics, regardless of their previous experience, this underlines the importance of the availability of training events and support networks to provide these individuals with the skills and confidence needed to produce their own population data. Empowering local analysts to produce their own small area population estimates and projections has the potential to provide a greater range of demographic information which could benefit their local communities and aid decision making. While the estimates and projections produced by NRS were seen by participants in this research as a useful and valuable resource, these statistics were only produced for a single defined area. Should users have the ability to produce their own estimates and projections, they could create them for a range of statistical and administrative geographies within their area, such as housing market, school catchment and social work areas, which would provide them with a wider range of meaningful demographic data.

Previous training events held in 2017 and 2019[12] which aimed to train NRS service users to produce small area population projections also demonstrated that there is an appetite for training of this type. While involved in the organisation and delivery of these training events as a teaching assistant, it was clear that there was a strong desire for more training networking opportunities which could allow local authorities to be more involved in the production of demographic data. While findings from this research suggest that financial pressures on local authorities may make it difficult for councils to release staff in order to attend training events; online resources may be developed, which users with some experience and skill in producing these projections, could consult to refresh their knowledge. Online resources could also overcome some of the confidence issues which were evident from participants in this research, with forums and support groups developed for local analysts across Scotland to discuss problems they are having and sharing resources and advice. While it may not be possible to recapture the teams of researchers which appeared to be a feature of the Regional Councils which existed prior to 1994, by developing virtual support networks across Scotland, individuals producing their own small area statistics may feel better supported and connected. This is particularly important for local authorities who only have a single analyst who deals with population statistics,

[12] https://www.nrscotland.gov.uk/statistics-and-data/statistics/statistics-by-theme/population/population-projections/population-and-household-sub-council-area-projections/user-guidance

and may feel isolated in their work. These online resources and forums could also be seen to have a lasting impact for future analysts. As this research also found evidence that knowledge and experience was not passed down within an organisation, with years of experience being lost when a staff member leaves the department; these online resources could also play an important role in the knowledge transfer process. By enabling experienced staff to share their knowledge online, it could be argued that the benefit of these years of experience will not only be of value to other analysts within one organisation, but across Scotland.

9.5.2: Communicating with Lay-Users

In addition to using online resources to provide information and training materials for the individuals who produce population estimates and projections, it is also important that there is adequate information available for lay-users of these statistics to allow them to interpret and use this information effectively. Another key finding of this research was that participants felt that individuals who do not routinely engage with population statistics found it difficult to differentiate between estimates, projections, and forecasts. This lack of awareness of the differences between estimates, projections, and forecasts has been documented in previous research, however, when consulting with participants of this research, it was evident that this lack of understanding was a significant issue which could lead to confusion and conflict, as well as the misuse of the data, which could have a wider impact on the local community.

To overcome this problem, more non-technical information could be provided alongside the release of the official population estimates and projections to clarify what the data is showing, how it can be used and its potential limitations. While this information already exists within the technical information and methodology notes published by NRS, this may need to be simplified. One example of a short and clear description of population estimates, projections and forecasts is provided by Hampshire County Council[13] (2020). In their guide, they provide a description of each type of population statistic (Mid-year Estimates, Long Term Projections and Small Area Forecasts) and explain when to use these figures. This guide also emphasises that all the population statistics, from estimates to projections are simply an estimation of the population size and should be treated as such, describing these figures as a 'suggestion' of what the population may be, and highlighting the potential for error. This resource, created by Hampshire County Council, may provide a useful template when looking for ways in which to ensure clarity concerning what different population statistics show, and how they can be used effectively. By including this type of information in the Contents section of NRS' downloadable tables, which contain the results of the estimates and projections, it

[13] https://www.hants.gov.uk/landplanningandenvironment/facts-figures/population/how-to-use

may provide the additional information some lay-users need to help differentiate between the different types of population statistics, and use the data effectively.

9.6: IMPLICATIONS FOR WIDER SOCIAL POLICY

As discussed previously, population estimates and projections have a wide range of uses, such as informing social policy, public health initiatives and in academic research. Small area population statistics are also becoming increasingly important as demand grows for more detailed statistics for small areas within local authorities. For this reason, it is important to consider how the findings of this research may impact upon the wider field of social policy.

One of the most significant results from this research in terms of its potential impact on social policy, is the issue of estimate bias relating to area deprivation. This finding could have a number of serious implications influencing not only funding directly but also impacting upon the accuracy of secondary statistics which affects resource allocation and policy making further. As previously discussed, population estimates are used in the production of many secondary statistics such as mortality rates and unemployment rates. These statistics are widely used in informing social policy and are used to identify a wide range of social issues. Should the bias observed in this research be consistently present in population estimates, rather than just a single event in 2011, the under-estimation of populations in the most deprived areas and the over estimation of the population in the least deprived areas may be masking problems related to social inequalities as a result of inaccurate data. Overall, both the bias present in small area population estimates themselves, and the resulting impact upon the accuracy of secondary statistics have the potential to undermine policies designed to reduce inequalities and may be exacerbating the gap between the wealthiest and poorest communities. In order to develop policies and target resources effectively, there must be some awareness of this potential bias present in the population figures, in particular, the under-estimation of areas experiencing the highest levels of deprivation.

As well as highlighting the potential for bias, the statistical modelling techniques used in this research as a method of measuring the impact of a range of area characteristics on error may provide valuable data, which could prove useful to planners and policy makers. Users of population statistics may find the results from these models beneficial when considering the likelihood of error present in any population estimates or projections. While the models produced in this research do not account for 100% of the variation between areas, they do demonstrate how some area characteristics may result in less accurate population statistics. This may mean that results from this research could provide users with additional information regarding the reliability of these population figures and aid them in their interpretation of estimates and projections. Despite this model not accounting for all of the variance in error, it could be employed by users of these statistics to calculate an approximate margin of error which may be found in their area based upon its demographic composition. This modelling of error could help users to understand how these factors may be affecting the accuracy of estimates and projections for each area and allow users to take into account the potential for error when using these statistics for planning or resource allocation.

In addition to the findings related to the accuracy of small area population estimates and projections, this research also highlights the importance of communication and co-operation between local and national levels of government. Chapter seven of this research discusses some of the issues related to local statistics produced by centralised, national agencies. This relationship between local and national governments has many implications for social policy, with effective policies taking into account the character and distribution of particular demographic groups at a neighbourhood and local level. An example of this has come to light during the Coronavirus pandemic, where local government agencies feel better placed to deliver testing and tracing services than national providers. As with participants in this current research, local government officials felt their local knowledge and understanding of their communities gave them a superior understanding of local infection hotspots and patterns of transmission, compared to centralised agencies (Hall, 2020; Paton, 2020; Gill et al, 2020). This mirrors some of the issues highlighted in this research, where local authorities felt better placed to provide knowledge of how their communities were organised, which in turn impacted upon how small area boundaries should be drawn or how some elements of population change may be restricted. This suggests that the comments made by participants in this research have a wider significance in the field of social policy, with the relationship between local and national governments and the tensions between them having significant effects on the planning and delivery of health and social policy.

9.7: LIMITATIONS AND OPPORTUNITIES FOR FUTURE RESEARCH

While this project has attempted to provide a comprehensive evaluation of small area population estimates and projections in Scotland, there are some limitations of this research which could be addressed in the future.

One such limitation of this research is that the results of this analysis simply give a snapshot of the accuracy of these population statistics for a single year. While this gives a valuable insight into how the error present in population estimates and projections varies between areas and provides some evidence to explain why this variation in accuracy occurs, these results may be limited in their usefulness. In the future, this research may be expanded to examine the accuracy of these population statistics across multiple years. This would involve comparing population estimates and projections to census data over a number of years. By evaluating estimates and projections over a series of years, it would better establish which factors impact upon the accuracy of small area population statistics, should some area characteristics be found to consistently increase error across multiple time periods. This comparison across years would be particularly useful when considering the relationship between estimate error and area deprivation presented in Chapter 5. As this finding may suggest a significant bias present in population estimates which could have important repercussions for the most vulnerable communities, it is important to establish whether this bias occurs consistently. If it is the case that small area population estimates are regularly more likely to under-estimate the most deprived areas, and over-estimate the most affluent areas, there would be significant implications arising concerning resource allocation and funding, the reliability of secondary statistics and the effectiveness of poverty reduction policies.

As well as expanding this research to evaluate small area estimates and projections over multiple years, this research could also be widened to evaluate these population statistics by sex as well as age. While both the small area population estimates and projections produced by NRS have age and sex detail, in this study population figures for males and females are grouped together in broad age bands for analysis. While this decision was made in order to ensure that estimates and projections for each age group contained a population size for which population statistics could be considered viable, some of the issues covered in the discussion chapter of this thesis may suggest that there would be some value in exploring the effect of sex on error. One way in which this may be done without fragmenting the population into ever smaller groups within sub-council areas, may be to include sex ratios within the multilevel model as an independent variable. As discussed previously, some behaviours which would influence the reliability of the data used in the production of population statistics, such as registering with a GP, may differ based upon sex. As a result, this may be a factor which should be included in any future study of this type and may explain some of the variation in error between areas which was not accounted for in the models conducted in this research.

The narrow range of methods examined in this study could also be seen as a potential limitation of this research. While this project specifically aimed to compare the methods currently used in Scotland to approaches used by statistical agencies elsewhere in the UK, and simple methods which would only require census data, there are other emerging methods which could have been included in this analysis.

In particular, methods which use only administrative rather than census data may be an increasingly important group of methods which could have been included in this study. As National Records of Scotland have stated that they wish to use the 2022 census (delayed from 2021 due to the Covid-19 pandemic), to explore how administrative data could be used *"to augment or replace NRS' data collected by the traditional census"* (Scotland's Census, 2020), it would be useful to have some knowledge of how estimates produced using solely administrative data would have fared historically, when compared to traditional census data. This is an issue which has been studied in England and Wales, with one such study conducted by Simpson et al (2017) comparing both census-based estimates and experimental administrative data based estimates to the 2011 census. In the future, the approach taken in this research by Simpson et al (2017) may be applied to Scotland, with administrative data methods included alongside the approaches examined in this thesis.

9.8: SUMMARY

Overall, this thesis makes many contributions to the existing body of knowledge regarding the issue of accuracy when producing small area population estimates and projections, and has the potential to have a positive impact beyond academia; in particular, the findings regarding the performance of alternative methods for producing both population estimates and projections. This research highlighted alternative methods which may improve the accuracy of small area population estimates, and also suggest that simpler projections methods may be a useful tool for local analysts seeking to produce their own low cost, short term projections. By examining the performance of these small area statistics across the whole of Scotland, it was possible to provide the first insight into how accurate users can expect these figures to be, while highlighting the factors which may result in a higher degree of accuracy in some areas, compared with others. Although the results of this research suggest that, overall, the current methods used in Scotland produce small area estimates and projections to a high standard, the findings which suggest the systematic under-estimation of the most deprived areas in the country, are a cause for concern due to the impact this bias could have on efforts to reduce inequalities and deprivation. In addition to this, results from this thesis also highlight the importance of communication between centralised agencies and local service users as well as the need for training programmes to further develop the role of local analysts in the production of small area estimates and projections. Taking advantage of local analysts' knowledge of their area as well as providing additional support to help these users feel more confident in their skills when producing and interpreting population statistics, can help to produce a deeper understanding of the demographic issues and trends experienced at a local level, as well as providing more accurate population data to help inform local planning and policy decision making.

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Appendix A

Data Zones Without Estimates/Excluded from Research

Data Zone	Local Authority	Reason
S01002296	City of Edinburgh	Unknown
S01003505	City of Glasgow	Population Zero
S01003031	City of Glasgow	Population Zero
S01003319	City of Glasgow	Population Zero
S01003548	City of Glasgow	Unknown

Appendix B

Data zones with data suppression

Data zone	Age Band	Year
S01000544	45-64	2001
S01000544	65+	2001
S01000777	45-64	2001
S01000777	65+	2001
S01002429	0-15	2001
S01002429	16-29	2001
S01004285	45-64	2001
S01004285	65+	2001
S01004316	45-64	2001
S01004316	65+	2001
S01000777	45-64	2002
S01000777	65+	2002
S01004285	45-64	2002
S01004285	65+	2002
S01004316	45-64	2002
S01004316	65+	2002
S01000777	45-64	2003
S01000777	65+	2003
S01004285	45-64	2003
S01004285	65+	2003
S01004316	45-64	2003
S01004316	65+	2003
S01000777	45-64	2004
S01000777	65+	2004
S01004285	45-64	2004
S01004285	65+	2004
S01004285	45-64	2005
S01004285	65+	2005
S01004285	45-64	2006
S01004285	65+	2006
S01004285	45-64	2007
S01004285	65+	2007
S01004285	45-64	2008
S01004285	65+	2008

S01000129	45-64	2009
S01000129	65+	2009
S01004285	45-64	2009
S01004285	65+	2009
S01003533	65+	2011
S01004316	65+	2011

Appendix C

SCAP Area by Local Authority

Local Authority	No. SCAP Areas	Min. Population	Max. Population	Mean Population	Area Type
Aberdeen	13	13878	21954	13309	Multi-Member Wards
Aberdeenshire	19	10009	16973	14497	Multi-Member Wards
Angus	8	10071	16725	14497	Multi-Member Wards
Argyll and Bute	8	3556	25717	11021	Housing Market Areas
Clackmannanshire	3	9806	21634	17147	Council Sub Areas
Dumfries & Galloway	4	24022	59452	37831	Multi-Member Wards
Dundee City	8	15958	21845	18409	Multi-Member Wards
East Ayrshire	9	10405	18434	13655	Multi-Member Wards
East Dunbartonshire	8	12221	14113	13128	Multi-Member Wards
East Lothian	7	10288	35841	16513	Multi-Member Wards
East Renfrewshire	3	23936	35442	30149	Multi-Member Wards
Edinburgh	17	22274	36838	28037	Multi-Member Wards
Eilean Siar	3	6110	13009	9228	Sub-Areas
Falkirk	6	15619	29635	23353	Sub-Council Areas
Fife	23	11892	22428	15878	Multi-Member Wards
Glasgow City	21	21991	33444	28279	Multi-Member Wards
Highland	10	9156	78417	23213	Housing Market Areas
Inverclyde	6	10713	17339	13581	Multi-Member Wards
Midlothian	6	10458	16554	13865	Multi-Member Wards
Moray	8	9222	15328	11662	Multi-Member Wards
North Ayrshire	6	12219	20970	16856	Neighbourhood Planning Areas
North Lanarkshire	20	12219	25664	16295	Multi-Member Wards
Orkney	5	2055	6351	4270	Housing Market Areas
Perth & Kinross	9	9452	25664	16295	Integrated Health and Social Partnership Areas
Renfrewshire	11	11621	19149	15901	Multi-Member Wards
Scottish Borders	11	8047	14345	10352	Multi-Member Wards
Shetland Islands	7	2668	5459	3310	Multi-Member Wards
South Ayrshire	6	9741	31720	18800	Locality Planning Areas
South Lanarkshire	14	5482	75986	22416	Community Areas
Stirling	7	11270	16832	12892	Multi-Member Wards
West Dunbartonshire	6	11277	17943	15120	Multi-Member Wards
West Lothian	9	14969	25501	19458	Multi-Member Wards

<u>**Appendix D**</u>

Patient register methodology notes

1	**FOI-2018-000095**
2	**Number of patients registered with a GP Practice in Scotland, by Data Zone 2001 and age group.**
3	
4	Data source: CHI database
5	
6	Notes:
7	1. Data is for all available patients and practices as of 30 September 2010/2011.
8	2. Patients were allocated to data zone based on their postcode. A number of patients in each year could not be mapped to data zone as their postcode was either missing or not recognised. These patients have been included in the data with the data zone "Unknown".
9	3. Cells with a value of 1 or 2 were suppressed in order to prevent the possible disclosure of personally identifiable information, in line with the ISD Statistical Disclosure Control Protocol.
10	4. The number of registered patients is inflated in comparison with National Records of Scotland estimates of population. There are a number of reasons for this difference:
11	- the CHI database will include people who have been given a CHI number but have since left the country to live for a period of time abroad.
12	- the CHI database will include overseas visitors who registered with a GP in Scotland or received screening services at a point in time during their visit.
13	- the CHI database will include students who have moved from Scotland during or after their studies but who have not registered elsewhere in the UK
14	
15	
16	

Metadata | Registered patients 2011

Appendix E

Log Transformation of APE

Appendix E

Log Transformation of APE

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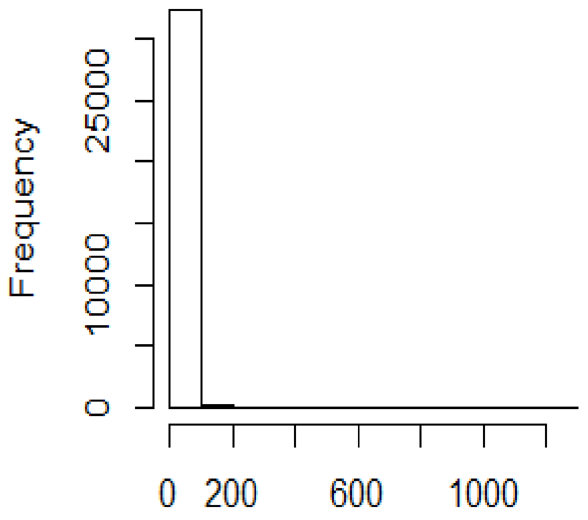
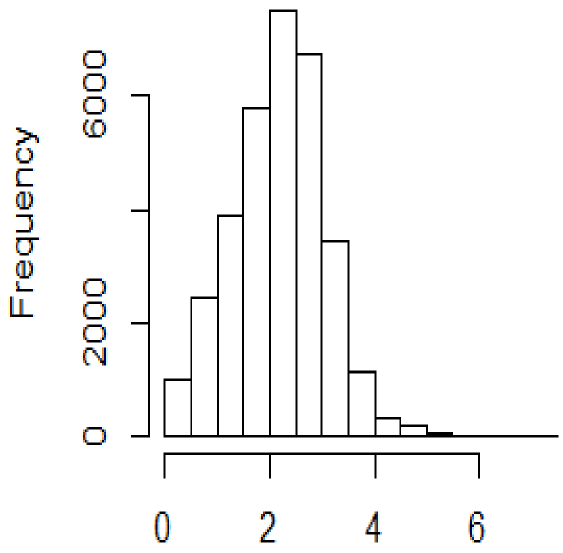
<tr><td>
</td><td>
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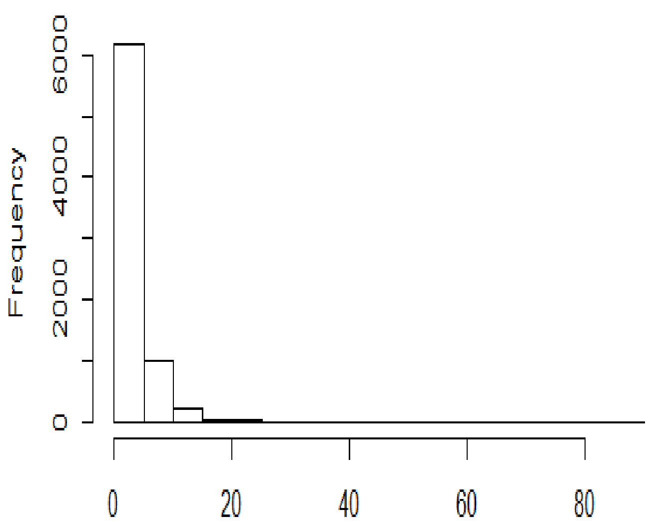
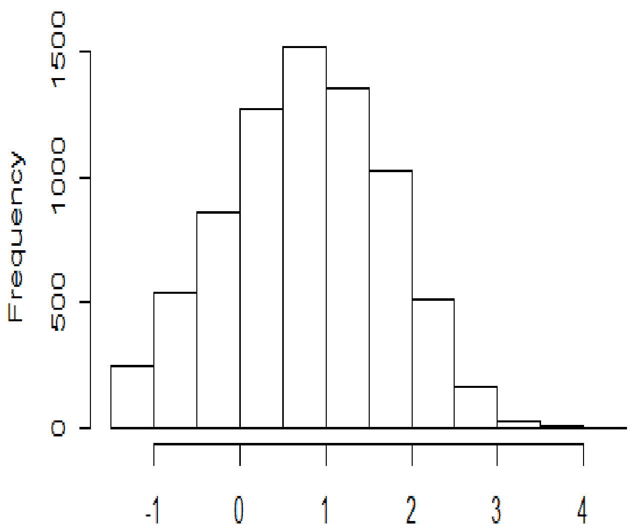
<tr><th colspan="2">Cohort Component Projection AP”E”</th></tr>
<tr><td>
</td><td>
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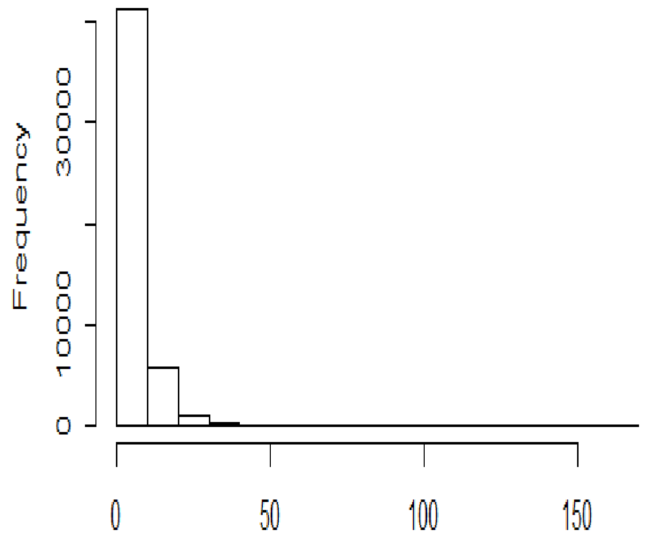
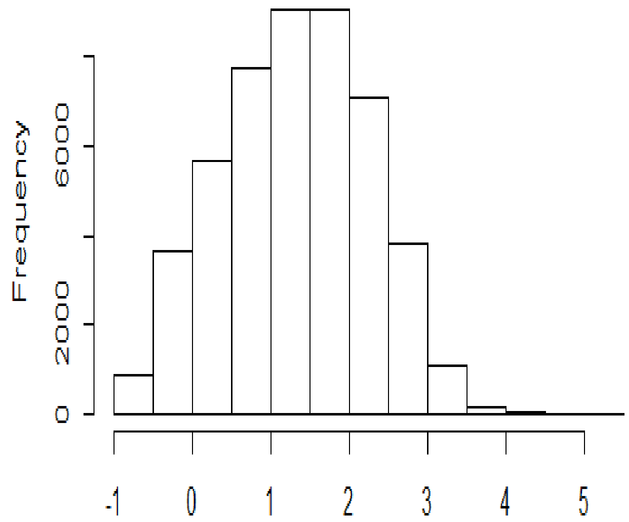
<tr><td>
</td><td>
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Appendix F

Participant Information Sheet

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PARTICIPANT INFORMATION SHEET

Invitation to Interview: Experiences of users of sub-council area population projections

I am a PhD student studying at the University of Edinburgh and working in collaboration with the National Records of Scotland (NRS) to evaluate sub-council area population projections and estimates in Scotland. By receiving this information, you have already taken part in the questionnaire stage of this research which is greatly appreciated. By completing this questionnaire, you have already helped to contribute to a growing body of information regarding how population data is used and interpreted across a range of sectors. Before taking part in this research further, I have providing some information about what would be involved in taking part in a follow up interview. Taking part in this interview is completely voluntary, if you have any further questions regarding these interviews please email me at s1820700@ed.ac.uk .

WHAT IS THE PURPOSE OF THIS STUDY?

The purpose of this research is to evaluate the accuracy of sub-council area population projections and estimates. While previous research has used statistical analysis to evaluate population projections, this research aims to explore the experiences of users of population statistics to discover the importance of accuracy and the consequences of error. In order to find out more about the experiences of users, the following topics will be covered;

- Cases where planners may have attempted to prevent a projection coming true
- When have inaccurate projections caused problems?
- Differences between projections and forecasts or variant projections
- Follow up questions from questionnaire responses

WHAT WILL THE INTERVIEW BE LIKE?

These interviews aim to accommodate participants as far as possible, therefore interviews can be conducted via Skype or telephone to fit with your schedule. The length of the interview will vary depending on how much you would like to discuss but will probably last around half an hour.

If you consent to take part in this interview, the process would involve an informal conversation about your experiences working with population projections and interviews. While there will be set topics (like those set out above) will be covered, you will also have an opportunity to discuss issues which are important to you and to express your opinions.

All participants in this research will remain anonymous, however you should be aware that by disclosing the region or local authority you are working in may make you identifiable. It is therefore at your discretion whether your location is disclosed. If an explicit area is not disclosed, a description can be used e.g. large urban centre, remote rural etc. All names of participants will be changed ensure anonymity.

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WHAT WILL HAPPEN TO MY DATA?

All participants in this study will be asked if the consent to interviews being recorded using a voice recorder. Following the recording, interviews will then be transcribed for analysis. All data will be kept secure in a password protected file and will be destroyed following the conclusion of this research. Participants can receive a copy of the transcript on request.

DO I HAVE TO TAKE PART?

No, taking part in an interview is completely your decision, with this information sheet provided to inform your decision. If you do wish to participate, you are free to stop the interview at any time and no further questions will be asked. If you withdraw from the interview at any time all recordings will be destroyed.

ARE THERE ANY RISKS?

There are no known risks of taking part in this study

WHO IS ORGANISING AND FUNDING THE RESEARCH?

This research is being conducted by Sarah Christison, a PhD student at the University of Edinburgh and is a collaborative research project with the National Records of Scotland. This project is funded by the Scottish Graduate School of Social Science. The contact information of others involved in this research are:

- Dr Alan Marshall – Supervisor (Alan.Marshall@ed.ac.uk)
- Denise Patrick – National Records of Scotland (denise.patrick@nrsscotland.ac.uk)

Thank you for reading this information sheet and for previously completing the questionnaire. If you would like any further information, please contact s1820700@ed.ac.uk .

School of Social Policy

Chrystal Macmillan Building,
15a George Square,
Edinburgh,
EH8 9LD

Email: s1820700@ed.ac.uk
Skype: sfc25@btinternet.com

Appendix G

Interview Schedule

1. How do you use population projection in your work?
    a. Do you refer to them frequently?

2. Can you tell be a bit about your experience producing population estimates?

3. Do you see population projections as a scenario to plan towards or as a sort of warning which you would introduce policy to prevent? Or a bit or both?

4. Have there ever been cases in your experience where policies have been proposed or implemented to prevent a projected scenario?

5. What is your thoughts on population projections and estimates being produced centrally by NRS, do you think locally produced statistics would make difference to their accuracy or usefulness?

6. Do you find small area or sub-council area population data useful?
    a. How does the usefulness differ from larger area population data?

7. Do you think your area has any unique characteristics that pose any particular challenges when projecting the future population?

8. In my own research, I found that projections for some areas were more accurate for some areas compared to others, has that been your experience?

9. Do you feel that the projections produced by NRS adequately indicate the potential range of potential error?

10. Have you had any experience where a population projection or estimate has had a large error and resulted in problems allocating resources or funding?

11. Do you feel that population projections are a useful tool in the planning process despite any potential error?

12. Do you have any further comments you would like to add or issues you would like to discuss?

Appendix H

Estimate Interaction Model

	Co-efficient	Standard Error	P Value
Intercept	2.13	0.01	<0.01
Reference (Cohort Component)			
Ratio Change Method	-0.020	0.013	0.13
Average Method	-0.060	0.013	<0.01
Constant Share Method	0.686	0.013	<0.01
Shift Share Method	0.684	0.013	<0.01
No Change Method	0.682	0.013	<0.01
Reference (0-15)			
16-29	0.291	0.013	<0.01
30-44	0.184	0.013	<0.01
45-64	-0.129	0.014	<0.01
65+	-0.044	0.013	<0.01
Arrived within a year (International Migration) (%)	0.014	0.005	<0.01
Communal Population (%)	0.005	0.001	<0.01
Non-White (%)	0.014	0.001	<0.01
One Person Household (%)	0.004	0.001	<0.01
Overcrowding (%)	-0.002	0.003	0.44
Population Growth (%)	0.002	0.000	<0.01
Population Size	-0.001	0.000	<0.01
Students (%)	0.010	0.001	<0.01
Unemployed (%)	0.009	0.003	<0.01
Unoccupied Housing (%)	0.014	0.001	<0.01
Ratio Change * 16-29	-0.089	0.019	<0.01
Ratio Change * 30-44	-0.183	0.019	<0.01
Ratio Change * 45-64	-0.108	0.020	<0.01
Ratio Change * 65+	-0.203	0.019	<0.01
Average * 16-29	-0.090	0.019	<0.01
Average * 30-44	-0.118	0.019	<0.01
Average * 45-64	-0.090	0.020	<0.01
Average * 65+	-0.136	0.019	<0.01
Constant Share * 16-29	0.028	0.019	0.14
Constant Share * 30-44	-0.192	0.019	<0.01
Constant Share * 45-64	-0.053	0.020	0.01
Constant Share * 65+	-0.041	0.019	0.03
Shift Share * 16-29	-0.343	0.019	<0.01
Shift Share * 30-44	-0.193	0.019	<0.01
Shift Share * 45-64	-0.032	0.020	0.11
Shift Share * 65+	-0.054	0.019	<0.01

No Change * 16-29	-0.338	0.019	<0.01
No Change * 30-44	-0.187	0.019	<0.01
No Change * 45-64	-0.034	0.020	0.09
No Change * 65+	-0.052	0.019	0.01
Ratio Change * Arrived within a year (International Migration) (%)	-0.015	0.005	<0.01
Ratio Change * Communal Population (%)	0.004	0.002	0.01
Ratio Change * Non-White (%)	0.000	0.001	0.83
Ratio Change * One Person Household (%)	-0.002	0.001	0.05
Ratio Change * Overcrowding (%)	-0.001	0.003	0.70
Ratio Change * Population Growth (%)	0.001	0.000	<0.01
Ratio Change * Population Size	0.000	0.000	<0.01
Ratio Change * Students (%)	-0.005	0.001	<0.01
Ratio Change * Unemployed (%)	0.002	0.003	0.43
Ratio Change * Unoccupied Housing (%)	-0.001	0.001	0.66
Average * Arrived within a year (International Migration) (%)	-0.010	0.005	0.06
Average * Communal Population (%)	0.002	0.002	0.13
Average * Non-White (%)	0.001	0.001	0.46
Average * One Person Household (%)	-0.001	0.001	0.13
Average * Overcrowding (%)	-0.004	0.003	0.22
Average * Population Growth (%)	0.001	0.000	0.00
Average * Population Size	0.000	0.000	<0.01
Average * Students (%)	-0.003	0.001	0.02
Average * Unemployed (%)	0.002	0.003	0.50
Average * Unoccupied Housing (%)	-0.002	0.001	0.18
Constant Share * Arrived within a year (International Migration) (%)	-0.016	0.005	<0.01
Constant Share * Communal Population (%)	-0.002	0.002	0.27
Constant Share * Non-White (%)	-0.005	0.001	<0.01
Constant Share * One Person Household (%)	-0.004	0.001	<0.01
Constant Share * Overcrowding (%)	-0.016	0.003	<0.01
Constant Share * Population Growth (%)	0.008	0.000	<0.01
Constant Share * Population Size	0.000	0.000	<0.01
Constant Share * Students (%)	-0.006	0.001	<0.01
Constant Share * Unemployed (%)	-0.011	0.003	<0.01
Constant Share * Unoccupied Housing (%)	-0.014	0.001	<0.01
Shift Share * Arrived within a year (International Migration) (%)	-0.013	0.005	0.01
Shift Share * Communal Population (%)	-0.003	0.002	0.09
Shift Share * Non-White (%)	-0.004	0.001	0.01
Shift Share * One Person Household (%)	-0.006	0.001	<0.01
Shift Share * Overcrowding (%)	-0.014	0.003	<0.01
Shift t Share * Population Growth (%)	0.009	0.000	<0.01
Shift Share * Population Size	0.000	0.000	<0.01
Shift Share * Students (%)	-0.009	0.001	<0.01
Shift Share * Unemployed (%)	0.000	0.003	0.98
Shift Share * Unoccupied Housing (%)	-0.018	0.001	<0.01

No Change * Arrived within a year (International Migration) (%)	-0.013	0.005	0.01
No Change * Communal Population (%)	-0.002	0.002	0.12
No Change * Non-White (%)	-0.004	0.001	0.01
No Change * One Person Household (%)	-0.006	0.001	<0.01
No Change * Overcrowding (%)	-0.014	0.003	<0.01
No Change * Population Growth (%)	0.009	0.000	<0.01
No Change * Population Size	0.000	0.000	<0.01
No Change * Students (%)	-0.009	0.001	<0.01
No Change * Unemployed (%)	0.000	0.003	1.00
No Change * Unoccupied Housing (%)	-0.017	0.001	<0.01

Appendix I

Projection Interaction Model

	Co-Efficient	Standard Error	P-Value
Intercept	**0.61**	**0.03**	**<0.01**
Method (Reference, Cohort Component)			
Arithmetic Method	0.01	0.04	0.83
Exponential Method	-0.03	0.04	0.45
Geometric Method	-0.03	0.04	0.45
Age (Reference, 0-15)			
16-29	0.06	0.03	0.03
30-44	-0.10	0.03	<0.01
45-64	-0.56	0.03	<0.01
65+	-0.54	0.03	<0.01
Year of Projection (Reference, Year 1)			
Year Two of Projection	0.28	0.03	<0.01
Year Three of Projection	0.48	0.03	<0.01
Year Four of Projection	0.65	0.03	<0.01
Year Five of Projection	0.83	0.03	<0.01
Arrived within a year (International Migration) (%)	0.08	0.03	0.01
Communal Population (%)	0.03	0.00	<0.01
Non-White (%)	0.01	0.01	0.24
One Person Household (%)	-0.01	0.00	0.07
Overcrowding (%)	0.03	0.01	<0.01
Population Growth (%)	0.00	0.00	<0.01
Population Size	0.00	0.00	<0.01
Students (%)	-0.01	0.01	0.27
Unemployed (%)	-0.03	0.02	0.03
Unoccupied Housing (%)	0.02	0.02	0.31
Arithmetic * 16-29	0.02	0.04	0.55
Arithmetic * 30-44	0.13	0.04	<0.01
Arithmetic * 45-64	0.05	0.04	0.20
Arithmetic * 65+	0.09	0.04	0.04
Exponential * 16-29	0.07	0.04	0.08
Exponential * 30-44	0.16	0.04	<0.01
Exponential * 45-64	0.13	0.04	<0.01
Exponential * 65+	0.11	0.04	0.01
Geometric *16-29	0.07	0.04	0.08
Geometric *30-44	0.16	0.04	<0.01
Geometric *45-64	0.13	0.04	<0.01
Geometric *65+	0.11	0.04	0.01

Arithmetic * Year Two of Projection	0.09	0.04	0.02
Arithmetic * Year Three of Projection	0.16	0.04	<0.01
Arithmetic * Year Four of Projection	0.19	0.04	<0.01
Arithmetic * Year Five of Projection	0.18	0.04	<0.01
Exponential * Year Two of Projection	0.09	0.04	0.02
Exponential * Year Three of Projection	0.17	0.04	<0.01
Exponential * Year Four of Projection	0.20	0.04	<0.01
Exponential * Year Five of Projection	0.19	0.04	<0.01
Geometric * Year Two of Projection	0.09	0.04	0.02
Geometric * Year Three of Projection	0.17	0.04	<0.01
Geometric * Year Four of Projection	0.20	0.04	<0.01
Geometric * Year Five of Projection	0.19	0.04	<0.01
Arithmetic * Arrived within a year (International Migration) (%)	-0.04	0.02	0.08
Arithmetic * Communal Population (%)	-0.01	0.00	0.11
Arithmetic * Non-White (%)	0.00	0.00	0.88
Arithmetic * One Person Household (%)	0.01	0.00	0.04
Arithmetic * Overcrowding (%)	-0.01	0.01	0.28
Arithmetic * Population Growth (%)	0.00	0.00	0.16
Arithmetic * Population Size	0.00	0.00	0.08
Arithmetic * Students (%)	0.00	0.01	0.46
Arithmetic * Unemployed (%)	0.01	0.01	0.49
Arithmetic * Unoccupied Housing (%)	-0.01	0.01	0.70
Exponential * Arrived within a year (International Migration) (%)	-0.04	0.02	0.10
Exponential * Communal Population (%)	-0.01	0.00	0.07
Exponential * Non-White (%)	0.00	0.00	0.95
Exponential * One Person Household (%)	0.00	0.00	0.30
Exponential * Overcrowding (%)	-0.01	0.01	0.41
Exponential * Population Growth (%)	0.00	0.00	0.01
Exponential * Population Size	0.00	0.00	0.16
Exponential * Students (%)	0.00	0.01	0.48
Exponential * Unemployed (%)	0.01	0.01	0.52
Exponential * Unoccupied Housing (%)	0.00	0.01	0.95
Geometric * Arrived within a year (International Migration) (%)	-0.04	0.02	0.10
Geometric * Communal Population (%)	-0.01	0.00	0.07
Geometric * Non-White (%)	0.00	0.00	0.95
Geometric * One Person Household (%)	0.00	0.00	0.30
Geometric * Overcrowding (%)	-0.01	0.01	0.41
Geometric * Population Growth (%)	0.00	0.00	0.01
Geometric * Population Size	0.00	0.00	0.16
Geometric * Students (%)	0.00	0.01	0.48
Geometric * Unemployed (%)	0.01	0.01	0.52
Geometric * Unoccupied Housing (%)	0.00	0.01	0.95

Appendix J

Alternative Bias Measures

SIMD Bias (1.25%)									
	Cohort Component			Ratio Change			Average		
	Accurate (%)	Over (%)	Under (%)	Accurate (%)	Over (%)	Under (%)	Accurate (%)	Over (%)	Under (%)
Decile									
1	11.54	27.54	60.92	16.15	35.38	48.46	14.00	31.23	54.77
2	15.41	32.20	52.39	16.64	37.75	45.61	14.79	36.06	49.15
3	12.44	35.02	52.53	17.97	39.17	42.86	16.13	36.71	47.16
4	16.67	34.57	48.77	16.98	40.74	42.28	16.05	36.11	47.84
5	14.29	38.10	47.62	17.82	43.93	38.25	16.28	39.32	44.39
6	15.41	44.68	39.91	20.34	43.61	36.06	19.72	43.14	37.13
7	16.13	43.16	40.71	17.51	44.70	37.79	17.97	43.78	38.25
8	14.62	51.23	34.15	17.54	52.00	30.46	17.54	52.31	30.15
9	15.05	47.16	37.79	21.35	46.70	31.95	18.59	47.00	34.41
10	14.92	48.92	36.15	18.46	46.31	35.23	17.54	48.00	34.46
Expected	**14.65**	**40.26**	**45.09**	**18.08**	**43.03**	**38.89**	**16.86**	**41.37**	**41.77**

Cohort Component Method: (X2= 214.37, df = 18, p<0.00)

Ratio Change Method: (X2= 104.1, df = 18, p<0.00)

Average Method: (X2= 186.2, df = 18, p<0.00

SIMD Bias (2.5%)									
	Cohort Component			Ratio Change			Average		
	Accurate (%)	Over (%)	Under (%)	Accurate (%)	Over (%)	Under (%)	Accurate (%)	Over (%)	Under (%)
Decile									
1	23.23	23.23	53.54	28.46	30.15	41.38	26.62	24.92	48.46
2	25.89	27.89	46.22	29.74	31.43	38.83	31.12	28.20	40.68
3	26.73	29.34	43.93	35.33	30.26	34.41	31.34	29.49	39.17
4	30.40	28.55	41.05	37.04	30.71	32.25	33.95	28.55	37.50
5	30.11	31.03	38.86	35.79	34.41	29.80	34.41	31.80	33.79
6	28.97	38.06	32.97	35.44	34.98	29.58	35.13	35.44	29.43
7	29.65	37.02	33.33	35.48	35.94	28.57	34.87	34.56	30.57
8	28.92	43.38	27.69	35.54	40.31	24.15	32.15	43.85	24.00
9	31.95	40.40	27.65	38.56	38.10	23.35	37.79	37.79	24.42
10	29.85	41.23	28.92	36.00	36.92	27.08	33.23	39.69	27.08
Expected	**28.57**	**34.02**	**37.42**	**34.74**	**34.32**	**30.94**	**33.06**	**33.43**	**33.51**

Cohort Component Method: (X2= 198.42, df = 18, p<0.00)

Ratio Change Method: (X2= 92.17, df = 18, p<0.00)

Average Method: (X2= 160.72, df = 18, p<0.00

Settlement Bias (2.5%)									
	Cohort Component			Ratio Change			Average		
	Accurate (%)	Over (%)	Under (%)	Accurate (%)	Over (%)	Under (%)	Accurate (%)	Over (%)	Under (%)
Settlement Type									
Accessible Rural	57.89	26.18	15.92	34.55	35.49	29.96	32.52	38.33	29.15
Accessible Small Towns	65.22	18.80	15.97	35.61	32.78	31.61	35.11	30.62	34.28
Large Urban Areas	57.51	22.41	20.08	32.45	36.33	31.22	31.22	33.51	35.27
Other Urban Areas	63.69	18.23	18.08	37.69	31.05	31.25	35.36	31.25	33.38
Remote Rural	53.78	30.21	16.02	29.29	42.33	28.38	29.06	43.25	27.69
Remote Small Towns	63.49	14.68	21.83	41.27	27.38	31.35	36.11	25.40	38.49
Expected	**60.17**	**21.43**	**18.40**	**34.74**	**34.32**	**30.94**	**33.06**	**33.43**	**33.51**

Cohort Component Method: (X2= 82.80, df = 10, p<0.00)

Ratio Change Method: (X2= 38.69, df = 10, p<0.00)

Average Method: (X2= 49.32, df = 10, p<0.00

Settlement Bias (1.25%)									
	Cohort Component			Ratio Change			Average		
	Accurate (%)	Over (%)	Under (%)	Accurate (%)	Over (%)	Under (%)	Accurate (%)	Over (%)	Under (%)
Settlement Type									
Accessible Rural	15.25	48.85	35.90	17.14	44.94	37.92	16.06	47.64	36.30
Accessible Small Towns	14.98	39.27	45.76	18.30	42.10	39.60	17.47	40.77	41.76
Large Urban Areas	12.65	38.45	48.90	17.67	44.08	38.24	15.88	40.86	43.27
Other Urban Areas	16.34	38.53	45.12	18.92	40.76	40.32	18.28	39.13	42.60
Remote Rural	16.02	49.66	34.32	15.56	49.89	34.55	16.48	49.43	34.10
Remote Small Towns	15.48	32.54	51.98	21.83	35.71	42.46	16.67	33.33	50.00
Expected	**14.65**	**40.26**	**45.09**	**18.08**	**43.03**	**38.89**	**16.86**	**41.37**	**41.77**

Cohort Component Method: (X2= 77.78, df = 10, p<0.00)

Ratio Change Method: (X2= 21.10, df = 10, p<0.02)

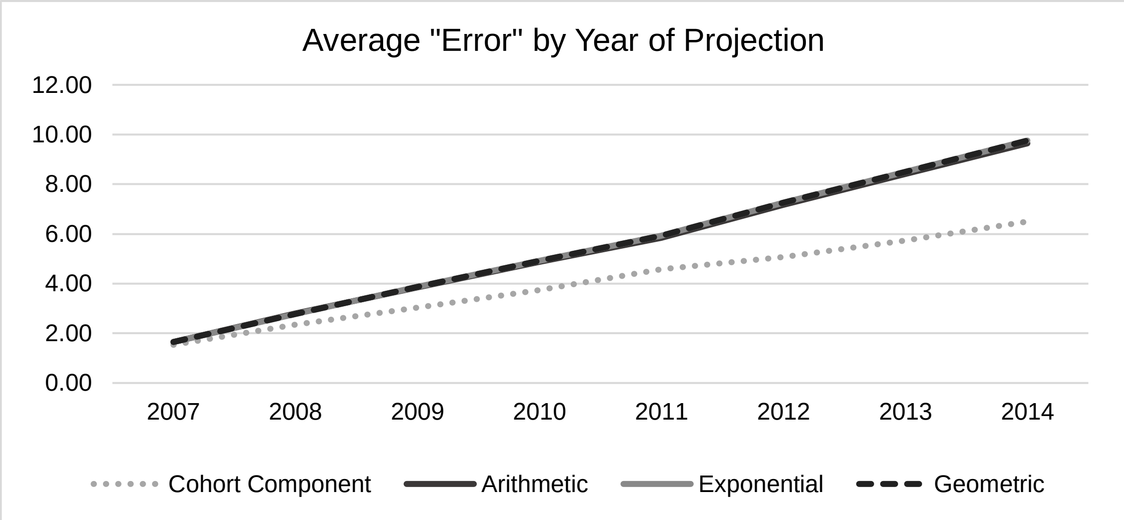
Average Method: (X2= 41.94, df = 10, p<0.0

Appendix K

Table 1: Range of Error – Projection Year 7 (2014)

		Min.	Max.	Mean	Standard Deviation
Cohort Component Method	**0-15**	0.05	88.61	8.06	8.34
	16-29	0.04	32.46	8.03	6.64
	30-44	0.00	30.69	8.90	6.71
	45-64	0.00	16.16	3.79	2.92
	65+	0.07	16.46	3.71	3.18
	Total	**0.01**	**15.39**	**4.50**	**3.36**
Arithmetic Method	**0-15**	0.09	100.43	11.17	10.52
	16-29	0.00	64.05	8.71	7.72
	30-44	0.13	39.60	13.29	8.77
	45-64	0.10	24.70	6.11	4.51
	65+	0.11	23.79	8.94	5.06
	Total	**0.02**	**18.20**	**4.67**	**3.75**
Geometric Method	**0-15**	0.00	160.52	10.68	13.04
	16-29	0.15	118.26	9.32	9.76
	30-44	0.23	44.31	13.30	9.27
	45-64	0.01	26.40	7.34	5.37
	65+	0.14	23.79	8.14	4.95
	Total	**0.03**	**25.62**	**4.83**	**3.89**
Exponential Method	**0-15**	0.00	160.52	10.68	13.04
	16-29	0.15	118.26	9.32	9.76
	30-44	0.23	44.31	13.30	9.27
	45-64	0.01	26.40	7.34	5.37
	65+	0.14	23.79	8.14	4.95
	Total	**0.03**	**25.62**	**4.83**	**3.89**

Figure 1: Average Error Over Time



Models

Table 2: Variance Component Model

	Variance	Standard Deviation
Data zones (Intercept)	0.08309	0.29
Residual	0.78556	0.89
	% Of Variability	
	Area Effects	**Other**
	33.13%	66.87%

Table 3: Method Model

	Coefficient	Standard Error	P Value
Intercept	**1.123**	**0.018**	**<0.01**
Reference (Cohort Component)			
Arithmetic Method	0.260	0.011	<0.01
Exponential Method	0.264	0.011	<0.01
Geometric Method	0.264	0.011	<0.01
Random Effects	**Variance**	**Standard Deviation**	
Data zones (Intercept)	0.08318	0.29	
Residual	0.77262	0.88	

Table 4: Method and Age Model

	Co-Efficient	Standard Error	P-Value
Intercept	1.234	0.020	**<0.01**
Method (Reference, Cohort Component)			
Arithmetic	0.260	0.011	<0.01
Geometric	0.264	0.011	<0.01
Exponential	0.264	0.011	<0.01
Age (Reference, 0-15)			
16-29	0.073	0.012	<0.01
30-44	0.104	0.012	<0.01
45-64	-0.457	0.012	<0.01
65+	-0.279	0.012	<0.01
Random Effects	**Variance**	**Standard Deviation**	
Data zones (Intercept)	0.08309	0.29	
Residual	0.78556	0.89	

Table 5: Method, Age and Projection Length Model

	Co-Efficient	Standard Error	P-Value
Intercept	**0.461**	**0.021**	**<0.01**
Method (Reference, Cohort Component)			
Arithmetic	0.260	0.009	<0.01
Geometric	0.264	0.009	<0.01
Exponential	0.264	0.009	<0.01
Age (Reference, 0-15)			
16-29	0.073	0.011	<0.01
30-44	0.104	0.011	<0.01
45-64	-0.457	0.011	<0.01
65+	-0.279	0.011	<0.01
Year of Projection (Reference: Year 1)			
Year 2 of Projection	0.324	0.013	<0.01
Year 3 of Projection	0.560	0.013	<0.01
Year 4 of Projection	0.743	0.013	<0.01
Year 5 of Projection	0.905	0.013	<0.01
Year 6 of Projection	1.080	0.013	<0.01
Year 7 of Projection	1.229	0.013	<0.01
Year 8 of Projection	1.344	0.013	<0.01
Random Effects	**Variance**	**Standard Deviation**	
Data zones (Intercept)	0.08465	0.29	
Residual	0.53684	0.73	

Table 6: Full Model

	Co-Efficient	Standard Error	P-Value
Intercept	0.478	0.019	**<0.01**
Method (Reference, Cohort Component)			
Arithmetic	0.260	0.009	<0.01
Geometric	0.264	0.009	<0.01
Exponential	0.264	0.009	<0.01
Age (Reference, 0-15)			
16-29	0.028	0.012	<0.01
30-44	0.101	0.011	0.02
45-64	-0.418	0.012	<0.01
65+	-0.361	0.012	<0.01
Year of Projection (Reference: Year 1)			
Year 2 of Projection	0.325	0.013	<0.01
Year 3 of Projection	0.561	0.013	<0.01
Year 4 of Projection	0.744	0.013	<0.01
Year 5 of Projection	0.907	0.013	<0.01
Year 6 of Projection	1.083	0.013	<0.01
Year 7 of Projection	1.231	0.013	<0.01
Year 8 of Projection	1.347	0.013	<0.01
Arrived within a year (International Migration) (%)	0.055	0.026	0.03
Communal Population (%)	0.023	0.001	<0.01
Non-White (%)	0.008	0.006	0.17
One Person Household (%)	-0.006	0.004	0.14
Overcrowding (%)	0.023	0.008	<0.01
Population Growth (%)	0.000	0.000	0.29
Population Size	0.000	0.000	<0.01
Students (%)	-0.008	0.006	0.20
Unemployed (%)	-0.049	0.013	0.04
Unoccupied Housing (%)	0.023	0.017	0.18
Random Effects	**Variance**	**Standard Deviation**	
Data zones (Intercept)	0.05654	0.2378	
Residual	0.53358	0.7305	